2022 Scientific Consensus Statement

Question 8.2 What are the key attributes of successful monitoring and evaluation programs to support coastal and marine water quality management, and what examples are there of innovative monitoring and evaluation frameworks, methods and approaches that are applicable to the Great Barrier Reef?

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Explanatory Notes for readers of the 2022 SCS Syntheses of Evidence

These explanatory notes were produced by the SCS Coordination Team and apply to all evidence syntheses in the 2022 SCS.

What is the Scientific Consensus Statement?

The Scientific Consensus Statement (SCS) on land use impacts on Great Barrier Reef (GBR) water quality and ecosystem condition brings together scientific evidence to understand how land-based activities can influence water quality in the GBR, and how these influences can be managed. The SCS is used as a key evidence-based document by policymakers when they are making decisions about managing GBR water quality. In particular, the SCS provides supporting information for the design, delivery and implementation of the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) which is a joint commitment of the Australian and Queensland governments. The Reef 2050 WQIP describes actions for improving the quality of the water that enters the GBR from the adjacent catchments. The SCS is updated periodically with the latest peer reviewed science.

C_2O Consulting was contracted by the Australian and Queensland governments to coordinate and deliver the 2022 SCS. The team at C_2O Consulting has many years of experience working on the water quality of the GBR and its catchment area and has been involved in the coordination and production of multiple iterations of the SCS since 2008.

The 2022 SCS addresses 30 priority questions that examine the influence of land-based runoff on the water quality of the GBR. The questions were developed in consultation with scientific experts, policy and management teams and other key stakeholders (e.g., representatives from agricultural, tourism, conservation, research and Traditional Owner groups). Authors were then appointed to each question via a formal Expression of Interest and a rigorous selection process. The 30 questions are organised into eight themes: values and threats, sediments and particulate nutrients, dissolved nutrients, pesticides, other pollutants, human dimensions, and future directions, that cover topics ranging from ecological processes, delivery and source, through to management options. Some questions are closely related, and as such readers are directed to Section 1.3 (Links to other questions) in this synthesis of evidence which identifies other 2022 SCS questions that might be of interest.

The geographic scope of interest is the GBR and its adjacent catchment area which contains 35 major river basins and six Natural Resource Management regions. The GBR ecosystems included in the scope of the reviews include coral reefs, seagrass meadows, pelagic, benthic and plankton communities, estuaries, mangroves, saltmarshes, freshwater wetlands and floodplain wetlands. In terms of marine extent, while the greatest areas of influence of land-based runoff are largely in the inshore and to a lesser extent, the midshelf areas of the GBR, the reviews have not been spatially constrained and scientific evidence from anywhere in the GBR is included where relevant for answering the question.

Method used to address the 2022 SCS Questions

Formal evidence review and synthesis methodologies are increasingly being used where science is needed to inform decision making, and have become a recognised international standard for accessing, appraising and synthesising scientific information. More specifically, 'evidence synthesis' is the process of identifying, compiling and combining relevant knowledge from multiple sources so it is readily available for decision makers[1]. The world's highest standard of evidence synthesis is a Systematic Review, which uses a highly prescriptive methodology to define the question and evidence needs, search for and appraise the quality of the evidence, and draw conclusions from the synthesis of this evidence.

In recent years there has been an emergence of evidence synthesis methods that involve some modifications of Systematic Reviews so that they can be conducted in a more timely and cost-effective

[1] Pullin A, Frampton G, Jongman R, Kohl C, Livoreil B, Lux A, ... & Wittmer, H. (2016) Selecting appropriate methods of knowledge synthesis to inform biodiversity policy. *Biodiversity and Conservation*, 25: 1285-1300. https://doi.org/10.1007/s10531-016-1131-9

manner. This suite of evidence synthesis products are referred to as **'Rapid Reviews'**[2]. These methods typically involve a reduced number of steps such as constraining the search effort, adjusting the extent of the quality assessment, and/or modifying the detail for data extraction, while still applying methods to minimise author bias in the searches, evidence appraisal and synthesis methods.

To accommodate the needs of GBR water quality policy and management, tailormade methods based on Rapid Review approaches were developed for the 2022 SCS by an independent expert in evidence-based syntheses for decision-making. The methods were initially reviewed by a small expert group with experience in GBR water quality science, then externally peer reviewed by three independent evidence synthesis experts.

Two methods were developed for the 2022 SCS:

- The **SCS Evidence Review** was used for questions that policy and management indicated were high priority and needed the highest confidence in the conclusions drawn from the evidence. The method includes an assessment of the reliability of all individual evidence items as an additional quality assurance step.
- The **SCS Evidence Summary** was used for all other questions, and while still providing a high level of confidence in the conclusions drawn, the method involves a less comprehensive quality assessment of individual evidence items.

Authors were asked to follow the methods, complete a standard template (this 'Synthesis of Evidence'), and extract data from literature in a standardised way to maximise transparency and ensure that a consistent approach was applied to all questions. Authors were provided with a Methods document, *'2022 Scientific Consensus Statement: Methods for the synthesis of evidence'*[3], containing detailed guidance and requirements for every step of the synthesis process. This was complemented by support from the SCS Coordination Team (led by C_2O Consulting) and the evidence synthesis expert to provide guidance throughout the drafting process including provision of step-by-step online training sessions for Authors, regular meetings to coordinate Authors within the Themes, and fortnightly or monthly question and answer sessions to clarify methods, discuss and address common issues.

The major steps of the Method are described below to assist readers in understanding the process used, structure and outputs of the synthesis of evidence:

1. **Describe the final interpretation of the question.** A description of the interpretation of the scope and intent of the question, including consultation with policy and management representatives where necessary, to ensure alignment with policy intentions. The description is supported by a conceptual diagram representing the major relationships relevant to the question, and definitions.
2. **Develop a search strategy**. The Method recommended that Authors used a S/PICO framework (Subject/Population, Exposure/Intervention, Comparator, Outcome), which could be used to break down the different elements of the question and helps to define and refine the search process. The S/PICO structure is the most commonly used structure in formal evidence synthesis methods[4].
3. **Define the criteria for the eligibility of evidence for the synthesis and conduct searches.** Authors were asked to establish **inclusion and exclusion criteria to define the eligibility of evidence** prior to starting the literature search. The Method recommended conducting a **systematic literature search** in at least **two online academic databases**. Searches were typically restricted to 1990 onwards (unless specified otherwise) following a review of the evidence for the previous (2017) SCS which indicated that this would encompass the majority of the evidence

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[2] Collins A, Coughlin D, Miller J, & Kirk S (2015) The production of quick scoping reviews and rapid evidence assessments: A how to guide. UK Government. https://www.gov.uk/government/publications/the-production-of-quick-scoping-reviews-and-rapid-evidence-assessments

[3] Richards R, Pineda MC, Sambrook K, Waterhouse J (2023) 2022 Scientific Consensus Statement: Methods for the synthesis of evidence. C_2O Consulting, Townsville, pp. 59.

[4] https://libguides.jcu.edu.au/systematic-review/define

base, and due to available resources. In addition, the geographic **scope of the search for evidence** depended on the nature of the question. For some questions, it was more appropriate only to focus on studies derived from the GBR region (e.g., the GBR context was essential to answer the question); for other questions, it was important to search for studies outside of the GBR (e.g., the question related to a research theme where there was little information available from the GBR). Authors were asked to provide a rationale for that decision in the synthesis. Results from the literature searches were screened against **inclusion and exclusion** criteria at the title and abstract review stage (**initial screening**). Literature that passed this initial screening was then read in full to determine the eligibility for use in the synthesis of evidence (**second screening**). Importantly, all literature had to be **peer reviewed and publicly available.** As well as journal articles, this meant that grey literature (e.g., technical reports) that had been externally peer reviewed (e.g., outside of organisation) and was publicly available, could be assessed as part of the synthesis of evidence.

4. **Extract data and information from the literature**. To compile the data and information that were used to address the question, **Authors were asked to complete a standard data extraction and appraisal spreadsheet**. Authors were assisted in tailoring this spreadsheet to meet the needs of their specific question.
5. **Undertake systematic appraisal of the evidence base**. Appraisal of the evidence is an important aspect of the synthesis of evidence as it provides the reader and/or decision-makers with valuable insights about the underlying evidence base. Each evidence item was assessed for its spatial, temporal and overall relevance to the question being addressed, and allocated a relative score. The body of evidence was then evaluated for overall relevance, the size of the evidence base (i.e., is it a well-researched topic or not), the diversity of studies (e.g., does it contain a mix of experimental, observational, reviews and modelling studies), and consistency of the findings (e.g., is there agreement or debate within the scientific literature). Collectively, these assessments were used to obtain an overall measure of the level of confidence of the evidence base, specifically using the overall relevance and consistency ratings. For example, a high confidence rating was allocated where there was high overall relevance and high consistency in the findings across a range of study types (e.g., modelling, observational and experimental). Questions using the **SCS Evidence Review Method** had an **additional quality assurance step**, through the assessment of reliability of all individual studies. This allowed Authors to identify where potential biases in the study design or the process used to draw conclusions might exist and offer insight into how reliable the scientific findings are for answering the priority SCS questions. This assessment considered the reliability of the study itself and enabled authors to place more or less emphasis on selected studies.
6. **Undertake a synthesis of the evidence and complete the evidence synthesis template** to address the question. Based on the previous steps, a narrative synthesis approach was used by authors to derive and summarise findings from the evidence.

Guidance for using the synthesis of evidence

Each synthesis of evidence contains three different levels of detail to present the process used and the findings of the evidence:

1. **Executive Summary**: This section brings together the evidence and findings reported in the main body of the document to provide a high-level overview of the question.
2. **Synthesis of Evidence:** This section contains the detailed identification, extraction and examination of evidence used to address the question.
   - ***Background***: Provides the context about why this question is important and explains how the Lead Author interpreted the question.
   - ***Method:*** Outlines the search terms used by Authors to find relevant literature (evidence items), which databases were used, and the inclusion and exclusion criteria.
   - ***Search Results:*** Contains details about the number of evidence items identified, sources, screening and the final number of evidence items used in the synthesis of evidence.

- ***Key Findings:*** The **main body of the synthesis**. It includes a summary of the study characteristics (e.g., how many, when, where, how), a deep dive into the body of evidence covering key findings, trends or patterns, consistency of findings among studies, uncertainties and limitations of the evidence, significance of the findings to policy, practice and research, knowledge gaps, Indigenous engagement, conclusions and the evidence appraisal.

3. **Evidence Statement:** Provides a succinct, high-level overview of the main findings for the question with supporting points. The Evidence Statement for each Question was provided as input to the 2022 Scientific Consensus Statement Summary and Conclusions.

While the Executive Summary and Evidence Statement provide a high-level overview of the question, it is **critical that any policy or management decisions are based on consideration of the full synthesis of evidence.** The GBR and its catchment area is large, with many different land uses, climates and habitats which result in considerable heterogeneity across its extent. Regional differences can be significant, and from a management perspective will therefore often need to be treated as separate entities to make the most effective decisions to support and protect GBR ecosystems. Evidence from this spatial variability is captured in the reviews as much as possible to enable this level of management decision to occur. Areas where there is high agreement or disagreement of findings in the body of evidence are also highlighted by authors in describing the consistency of the evidence. In many cases authors also offer an explanation for this consistency.

Peer Review and Quality Assurance

Each synthesis of evidence was peer reviewed, following a similar process to indexed scientific journals. An Editorial Board, endorsed by the Australian Chief Scientist, managed the process. The Australian Chief Scientist also provided oversight and assurance about the design of the peer review process. The Editorial Board consisted of an Editor-in-Chief and six Editors with editorial expertise in indexed scientific journals. Each question had a Lead and Second Editor. Reviewers were approached based on skills and knowledge relevant to each question and appointed following a strict conflict of interest process. Each question had a minimum of two reviewers, one with GBR-relevant expertise, and a second 'external' reviewer (i.e., international or from elsewhere in Australia). Reviewers completed a peer review template which included a series of standard questions about the quality, rigour and content of the synthesis, and provided a recommendation (i.e., accept, minor revisions, major revisions). Authors were required to respond to all comments made by reviewers and Editors, revise the synthesis and provide evidence of changes. The Lead and Second Editors had the authority to endorse the synthesis following peer review or request further review/iterations.

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Executive Summary

Question

Question 8.2 What are the key attributes of successful monitoring and evaluation programs to support coastal and marine water quality management, and what examples are there of innovative monitoring frameworks, methods and approaches that are applicable to the Great Barrier Reef?

Background

The scope of this question was to review attributes of successful monitoring and evaluation (M&E) programs for coastal and marine ecosystems and identify potential M&E frameworks or components of M&E programs that could be beneficial for coastal and marine water quality management on the Great Barrier Reef (GBR). Whilst the GBR has well developed monitoring programs that have provided historical data for corals, seagrasses, crown-of-thorns starfish (COTS), fisheries, and water quality, the high-quality, high density ecological data has not always provided a clear path for achieving positive environmental outcomes through these programs.

Success can be measured in many ways and have different meanings to different people. For example, positive environmental and societal change related to M&E programs may entail a move away from a single pressure-state response through to the development of integrated frameworks across ecosystems, pressures, stakeholders and policy. In the simplest and broadest of terms, success in M&E is that it has been designed to assess whether policy implementation has been successful and to identify factors that have led to successful or unsuccessful implementation. However, to identify a single program which can demonstrate this categorically is difficult, given the varied and complex nature of marine M&E. Thus, this review breaks this question down, and looks to identify success as a series of attributes within programs, or programs with specific attributes that have contributed to success of positive implementations for the marine environment.

Methods

- A formal Rapid Review approach was used for the 2022 Scientific Consensus Statement (SCS) synthesis of evidence. Rapid reviews are a systematic review with a simplification or omission of some steps to accommodate the time and resources available[5]. For the SCS, this applies to the search effort, quality appraisal of evidence and the amount of data extracted. The process has well-defined steps enabling fit-for-purpose evidence to be searched, retrieved, assessed and synthesised into final products to inform policy. For this question, an Evidence Summary method was used.
- Search locations were Scopus, Elsevier Science Direct and Google Scholar.
- Main source of evidence: National and international studies plus GBR studies for context of current M&E programs.
- From the initial keyword search 13,711 studies were identified through online searches for peer reviewed and published literature and a further 70 studies were added manually from personal collections and the SCS database, which represented 0.5% of the total items. After initial and secondary screenings, 244 studies were found eligible for inclusion in the synthesis of evidence.

Method limitations and caveats to using this Evidence Summary

For this Evidence Summary, the following caveats or limitations should be noted when applying the findings for policy or management purposes:

- The review only included studies written in English.
- Only two academic databases were searched.

[5] Cook CN, Nichols SJ, Webb JA, Fuller RA, Richards RM (2017) Simplifying the selection of evidence synthesis methods to inform environmental decisions: A guide for decision makers and scientists. *Biological Conservation* 213: 135-145 https://doi.org/10.1016/j.biocon.2017.07.004

- The focus was on frameworks with relevance to the GBR and did not focus on details around methods, technologies and/or indicators to keep scope manageable.
- Papers that demonstrated positive benefits from the use of different M&E methods were included though the definition of success was varied throughout the literature.
- The review does not include papers about the technical information collected in the GBR M&E for water quality.
- To limit the large number of returns given the searches extended to international literature, specific terms around selected M&E approaches were used which are known for representing integrated approaches such as Driver-Pressure-State-Impact-Response (DPSIR) frameworks.
- Given the extremely high number of returns on research that was associated with M&E for marine and coastal areas, only literature post-2000 was included (with the exception of four papers). M&E is a dynamic landscape, constantly changing and evolving, and the restriction to recent years will be the most relevant to the GBR and current policy setting. The four papers included from pre-2000 including two papers on the development of M&E in the GBR, a seminal integrated study from Florida and a paper defining the origin of ecological goods and services.
- Exclusion criteria focused mainly on studies that were not directly comparable to the GBR and water quality monitoring or did not discuss any elements of success or positive changes.

Key Findings

Summary of evidence to 2022

- The GBR has well-established governance structures that have evolved over 45 years. Monitoring has played a critical role in demonstrating management performance and guiding desired outcomes. Good planning, including the identification of indicators and targets in the GBR, has been important for effective implementation, monitoring and evaluation.
- The GBR is managed as a multi-zone marine protected area to accommodate diverse stakeholders and their impacts. However, agreement on zoning, fishing, and marine protection has been a longstanding issue, and the management of coastal water quality as a catchment-to-coast issue faces difficulties due to divergent opinions among government agencies and stakeholders impacting on the success of M&E programs.
- The primary integrated coastal and marine water quality monitoring and evaluation programs in the GBR are the Reef 2050 Integrated Monitoring and Reporting Program, the Paddock to Reef Integrated Monitoring Modelling and Reporting program and the monitoring and reporting conducted as part of the regional report card partnerships.
- Monitoring is a critical element that involves the collection of data and information before, during and after implementation. Successful evaluation involves the systematic assessment of a project or program’s design, its implementation, and outcomes to determine whether original objectives were achieved, identify lessons learned, deliver learning and demonstrate accountability. Both these components need to work together and provide a clear pathway to positive change.
- Across the studies included in this review, success was associated with the inclusion of holistic monitoring and evaluation approaches across multiple values, beneficiaries, and disciplines. Success associated with any M&E program should always encompass clear understanding of anthropogenic change, the technical ability to link that change to an activity or sector, transparent pathways for positive management action, recognition and incorporation of divergent societal concerns and policy tools that support sustainable outcomes for the marine environment. These are broad and ambitious success criteria, and rarely, if at all, has one M&E program delivered all of this from end to end. What has been done, and explored in this review are attributes of M&E programs that provide pathways to achieving components of success.
- Many of the water quality pressures that impact on the ecological state of the GBR are not being successfully mitigated or are mitigated with only partial success.
- Lack of action and mitigation across other international coastal and marine water quality programs has seen a growing emphasis of integrated and holistic approaches to M&E,

recognising that conventional program designs do not address the complexity of the interactions between ecological, social and economic values, drivers and outcomes.

- M&E programs that contribute to positive changes through management actions include those that engage and represent the values of a diverse range of stakeholders that are impacted by the decision making. This is particularly true for local and regional stakeholders but can also extend to international partnerships, large conservation agencies and international frameworks.
- Successful outcomes have also been associated with the adoption of system drivers, pressures, state, impact and responses (typically shortened to DPSIR) framework, recognise ecosystem services and marine natural capital, adopt multi-disciplinary frameworks and report on the interactions between environmental and human health, and support connections to people through the use of citizen science.
- Incorporation of natural capital into monitoring programs has also been a successful way to bring together the system linkages between ecology, goods and services, and benefits to human wellbeing. Integrated approaches like the cross-sectoral and transdisciplinary One Health monitoring and evaluation framework, that emphasises the interconnections between the health of humans and ecosystems, are highly applicable to the GBR as a potential monitoring and evaluation approach. These holistic approaches also recognise the benefits of projects and programs that are relevant to a range of end-users.
- Whilst components of some of these approaches have already been used within GBR monitoring, there are still many concepts embedded in the approaches that could offer new paradigms and direction for GBR M&E for coastal and marine water quality.
- The collection of data, and the ability to be confident in tracking and understanding change is only one small part of M&E. In some respects, the success of a monitoring program is the ability to drive change, using the information generated to track change, and to create a narrative where environmental sustainability is strongly supported by society. There are many types of M&E practices that may be useful to GBR long-term monitoring by adding additional aspects that provide a space where both government and society can be part of an adaptive program.

Recent findings 2016-2022

- The Reef 2050 Integrated Monitoring and Reporting Program and the Paddock to Reef Integrated Monitoring Modelling and Reporting programs are among the most comprehensive and integrated catchment to reef monitoring programs in the world.
- Improvements have continually been made to the M&E of coastal and marine water quality in the GBR. The GBR monitoring and evaluation process involves multiple institutions, academics, managers and stakeholders.
- M&E programs in the GBR already recognise the links between drivers, pressures and state through the reporting of environmental, social and economic indicators. They also attempt to merge the complexities of the pressure-state response in user-friendly visual portals and report card formats, although the connections between environment and people, health and citizen science are not explored in great detail.
- Despite intergovernmental arrangements enabling cooperation between federal and state governments, there are challenges which have hindered the success of the M&E programs.
- The coastal and marine water quality program collects a large volume of information and has been effective in tracking changes, however despite some key indicators shifting in a negative trajectory, there is still disagreement among stakeholders regarding the extent of impact and necessary changes.
- Collaborative decision-making is crucial for GBR management, but there have been both successes and failures in engaging stakeholders and improving water quality. Integrated adaptive catchment management requires linking biophysical, social and economic systems.
- Greater engagement of the community in data collection, but also in evaluation and decision making, would enhance monitoring and evaluation programs for the GBR and potentially lead to greater acceptance and support of changed management arrangements.

- Management in the GBR has been focused on management interventions from state and federal policy. However, Australia is now increasingly becoming part of the international community, identifying ambitious targets for climate emissions. Water quality issues, whilst mitigated at local levels, are part of an international problem, with agencies such as the United Nations developing frameworks that address commonalities of issues and solutions across the world.
- Citizen science is not just about local citizens working within the GBR but can become part of a global M&E approach that celebrates citizen science and incorporates the community as part of an inter-connected marine environment.
- Potential improvements drawn from the global evidence base include greater recognition and quantification of complex social, cultural, economic and environmental values and their interconnections, strengthening of multi-disciplinary frameworks to link to human health, and greater community engagement including direct participation in monitoring programs.

Significance for policy, practice, and research

From the 1980s, a growing awareness of water quality and the connections between catchment and coastal waters was the catalyst for the original GBR water quality management program and the ongoing iterations of water quality and reef monitoring. Now, a suite of interventions is in play including marine protected areas, COTS removal and large-scale interventions explored via the Reef Resilience and Adaptation Program (RRAP program). Many of these interventions focus on adjusting components of the coral populations to improve resilience of the coral community or large-scale activities such as cloud darkening. In contrast, an important intervention strategy is the reduction of pollution loads to improve resilience by the removal of a pressure where the management of the pressures is spatially disparate and temporally separate from the impact. Recognition of the role that improving water quality has for the overall GBR outlook has led to the current Paddock to Reef (P2R) program, with a network of monitoring and evaluation tools using indicators to track change from the sub-catchment to the coastal zone

A key component of success for M&E programs is the ability to report on complex interactions, where the drivers and pressures within the catchment to coast system are linked directly to ecological state and impact. Despite the multiple different approaches to implementing integrated frameworks, much of the success of this approach lies in simple messaging, with the connections between the human induced drivers and pressures clearly linked to state, impact and human welfare.

Key uncertainties and/or limitations

There were several limitations for this review that were associated with the challenges of addressing a very broad question. Concepts identified in the original search terms retrieved thousands of papers, making it difficult and time consuming to identify programs and components that could be used in this assessment of M&E, and to identify findings that would provide useful information to policy and management on potential improvements that could be made to the existing programs. This was still the case even when search terms were restricted, and the exclusion criteria were applied, and the relevance of the papers were assessed in terms of the type of monitoring and evaluation programs that could be relevant to the GBR context. In addition, as noted in this review, the GBR is one of the most monitored (and evaluated) systems in the world, and some improvements can be minor, or could be included within current programs but the identification of those improvements would require an in-depth knowledge of the details of all existing programs which was outside the scope of this review.

Novel approaches such as One Health and monitoring the linkages between environmental and human health are still relatively new in terms of measuring change and response. This has limited the ability of the review to identify where these approaches have been successful in driving positive change and mitigating negative activities. Much of the success responses were about the integration and increased communication with a range of stakeholders. Recommendations to reduce uncertainty would be to revisit this question in the next SCS to look at programs which have incorporated aspects of the components presented in this review and evaluate the long-term changes associated with these integrated frameworks.

Evidence appraisal

The quantity of evidence was considered High with 244 papers selected for the review and a range of papers across different types of monitoring and evaluation (M&E) provided High diversity for the different type of programs that were reviewed for this question. The High diversity of studies used for the synthesis was supported by the range of papers across different topics of M&E including citizen science/community consultation (30), DPSIR (39), GBR governance (9), GBR scene setting (57), Integrated approaches (28), marine natural capital (39), MPAs (5), One Health (28) and Technology (9). The depth and breadth of monitoring programs, and differences in M&E explored in the papers provide a good range of complexity and diversity in the types of M&E components.

Confidence was Moderate, based on Moderate consistency and High overall relevance of the body of evidence. This Moderate confidence reflects the large body of literature that exists around different approaches in M&E providing high diversity, but the breadth of the literature (components, geographical locations and approaches) influences the lower score of moderate for the consistency rating. Although relevance is high (7.1) the lower ratings for temporal and spatial relevance reflect that the majority of the literature (75%) was taken from international case studies. There were several GBR relevant studies around new, emerging and different approaches to M&E, but they represented a much smaller subset (25%) and many of those were included as background information around current M&E. Some loss of confidence could also be associated with the broader M&E categories, with many of the studies having relevant outcomes, but not always focused on coastal and marine water quality. Many of these broader studies were excluded in the second screening but there was still a very broad range of approaches and different types of terminology included in the final set of papers.

1. Background

Monitoring and evaluation (M&E) of coastal and marine water quality systems is an essential tool that provides an assessment of environmental and management change. Jacobson et al. (2014) describe it as a critical component of adaptive management, enabling adjustment of management actions and the assumptions upon which they are based. Successful monitoring is the collection of data, both during and after project implementation to improve current and future decision making and a critical element in the project design and implementation. Successful evaluation is the systematic assessment of an intervention's design, implementation and outcomes to deliver learning and accountability. Overall, successful program design for M&E depends on clear program objectives and ensuring fit for purpose design against those program objectives (Kusek, 2010). Success in M&E is most clearly seen when both monitoring and evaluation are interlinked, with monitoring measuring the effectiveness of actions, whereas evaluation involves the interpretation of that information (Jacobson et al., 2014; Kusek, 2010).

Much of the monitoring and assessment processes of the GBR report information on an indicator level, focusing reporting of indicators within each category of corals, fish and water quality (among others). The developing Reef 2050 Integrated Monitoring and Reporting Program (RIMReP) is now reporting many of these indicators together, merging the complexities of the pressure-state response in visual, user friendly portals and report card formats. However, indicators are still presented separately from any measurable economic or social indicators, where the scale of the impact can be linked directly to other non-environmental measures of state.

Monitoring and evaluation in the GBR has progressed through several stages, responding to the complex interactions between the catchment and health of the GBR. It has needed to meet the demands of a multi-use system with multiple stakeholders in one of the most unique and well-known marine ecosystems in the world. The GBR faces a multitude of challenges caused by human activities such as climate change, overfishing, habitat destruction, and pollution. Such ecological changes have negative impacts on the communities who depend on the GBR for economic, cultural and social benefits. Monitoring and evaluation frameworks should identify, and respond to, many of the large challenges of monitoring such a complex system with diverse stakeholders, e.g., large spatial scale, time lags, inter-annual variability, multiple values and beneficiaries and in doing so, identify potentially suitable approaches that incorporate this complexity in M&E.

There are currently two main components to M&E of water quality in the GBR and adjacent catchments and progress towards achieving water quality goals as part of the Reef 2050 Water Quality Improvement Plan (Coggan et al., 2021). The first component includes programs oriented to catchment management such as monitoring and modelling of pollutant loads reaching the coast, measurements of ground cover, adoption of best management practices, and the human dimensions around the uptake of management practices. The second component involves *in situ* coastal and marine water quality monitoring and flood plume monitoring using remote sensing (Haynes et al., 2007; Petus et al., 2019; Thorburn & Wilkinson, 2013). In addition, there are five regional report cards that provide more information about what is happening in those regions (Commonwealth of Australia, 2021).

Although this review is focused on understanding key attributes of successful M&E programs to support coastal and marine water quality management, an initial, rapid assessment of the existing coastal and marine water quality M&E programs was warranted. It was important to have that context to be able to answer how other M&E frameworks, methods, and approaches could be applicable to the GBR and would help support GBR coastal and marine water quality management. Policy actions such as the establishment of marine protected areas can and have been successful in protecting marine assets, however without consensus across social and political barriers, the long-term success can be limited (Bawole et al., 2013; Cvitanovic et al., 2013; Foale & Manele, 2004; Francis et al., 2002).

The existing monitoring programs cover a wide range of areas, including the marine environment, water quality, tourism and recreation, fisheries, and socio-economic trends such as community benefits. Data and reporting pathways are well established, with high quality communication products allowing dissemination of data to multiple stakeholders (Hedge et al., 2017). Data analysis and data integration are a critical component for successful monitoring and evaluation (Flower et al., 2017; Hedge et al., 2017; Opishinski et al., 2001). Integration of the data collected in the GBR monitoring programs takes place under RIMReP. The implementation of RIMReP is a core activity under the Reef 2050 Long Term Sustainability Plan, an “overarching long-term strategy for the GBR to coordinate protection and improve resilience” (Emslie et al., 2020), and is attempting to facilitate better alignment between the current 90 or more monitoring programs that are operating in the GBR Marine Park (Hedge et al., 2017).

Coastal and marine water quality is currently measured in two ways. First, eReefs, a state-of-the-art bespoke coupled hydrodynamic – biogeochemical model which models water quality and is validated by a wide range of water quality measurements and where information for the Reef Water Quality Report Card is derived (Baird et al., 2021; Chen et al., 2011; Steven et al., 2019). Second, from the inshore water quality component of the Marine Monitoring Program (MMP), which collects *in situ* data on physico-chemical water quality parameters including nutrients and sediment concentrations primarily in four Natural Resource Management (NRM) regions (Brodie et al., 2012; Moran et al., 2023; Schaffelke et al., 2008) and wet season flood plume exposure and risk to marine communities (Petus et al., 2016; 2019). The main objective of the existing marine water quality program is to “assess temporal and spatial trends in inshore marine water quality and link pollutant concentrations to end-of-catchment loads” (Lloyd-Jones et al., 2022).

Prior to discussions on successful M&E criteria, there are a few key observations about the existing water quality M&E programs.

- The inshore water quality component of the MMP is not currently integrated into the Reef Water Quality Report Card, which limits the utility of the collected data (Moran et al., 2023).
- While the targets for the end-of catchment loads have been developed to be ecologically relevant (Brodie et al., 2012; 2017), neither the Reef Water Quality Report Card nor the inshore water quality monitoring report systematically assess the link between pollutant concentrations and end-of-catchment loads, which is part of the main objective of the coastal and marine water quality monitoring program (Kroon, 2012).
- In addition, the most recent Reef Water Quality Report Card and Outlook Report (2019) indicates that progress towards achieving several of the water quality and catchment management targets is lagging (Reef Water Quality Report Card 2020). Whist this lack of success in positive change is due to many complex environmental and social factors, M&E for the GBR should support better implementation and enforcement of a multi-use marine park, thus not only reporting the trajectory of change, but providing mechanisms to influence and improve that trajectory.

In response to recognising that M&E could be a catalyst for positive change, this review identifies successful M&E programs that support coastal and marine water quality management and provide a baseline from which policy implementation can lead to improvements, such as meeting agreed water quality targets.

In this context, the review focused on two main aspects:

1) Are there other approaches that have been used to better link coastal and marine water quality data to a range of actions and stakeholders?

2) Since progress towards achieving several water quality and catchment management targets is lagging, which ultimately drive coastal and marine water quality, are there additional M&E frameworks that could shed more light on why targets are not being achieved, which could be used to inform management?

1.1 Question

Primary question	**Q8.2** What are the key attributes of successful monitoring and evaluation programs to support coastal and marine water quality management, and what examples are there of innovative monitoring and evaluation frameworks, methods and approaches that are applicable to the Great Barrier Reef?

Clarifying the question

The GBR is a vast area to monitor, and evaluation of changes for coastal and marine water quality management has depended on the analysis of trends to best capture the health of the GBR. However, the current approach can still be improved with a need to look more broadly across existing and new developments that could be integrated into existing programs. This review provides an opportunity to look beyond what is currently being done and consider new and upcoming approaches outside of the GBR that are relevant to monitoring but also other aspects of evaluation. There is a fine line in acknowledging the success of the large, multi-institutional, multi-stakeholder, highly technical GBR water quality program, and then looking beyond the current program for improvements to an already integrated, long-term, comprehensive monitoring program. The focus of the question is then to consider components of other systems around the world that could be used to improve aspects of the current M&E, for example, through consideration of alternative frameworks or adjustment of existing ones.

What are the key attributes of successful M&E programs to support coastal and marine water quality management, and what opportunities are there for integration of innovative M&E frameworks, methods and approaches in the GBR?

What are the key attributes of successful M&E programs

M&E programs for catchment to coast management should encompass two separate processes. Monitoring is the periodic assessment of the effectiveness of management practices to determine whether they are proceeding as planned. Evaluation involves the assessment of the programs towards the achievement of results, milestones, and impact of the outcomes based on the use of performance indicators. A successful program meets its initial objectives and answers the questions it was designed to address - the attributes of those successful programs are what will be identified in this review.

Success can be measured in many ways and have different meanings to different people. In the simplest and broadest of terms, success in M&E is that it has been designed to assess whether policy implementation has been successful and to identify factors that have led to successful or unsuccessful implementation. However, to identify a single program which can demonstrate this categorically is difficult, given the varied and complex nature of marine M&E. Thus, this review breaks this question down, and looks to identify success as a series of attributes within programs, or programs with specific attributes that have contributed to success of positive implementations for the marine environment.

To support coastal and marine water quality management,

Coastal and marine water quality management is a vital aspect of ensuring the health and sustainability of oceans and coastal ecosystems. It involves the implementation of measures to monitor, protect, and improve the quality of water in these environments (Creighton et al., 2021; Waterhouse et al., 2012). Effective management strategies aim to mitigate and prevent pollution, reduce nutrient runoff, control sedimentation, and address other sources of contamination that can negatively impact water quality (Devlin & Brodie, 2023). This includes regulating industrial discharges, sewage treatment, and agricultural practices to minimise pollutants entering coastal and marine waters. Management intervention can be both place-based, such as the protection and restoration of ecosystems or the implementation of more sustainable land management practices, or they can be policy-based, such as regulations around vegetation clearing (Wakwella et al., 2023).

and what examples are there of innovative M&E frameworks, Existing GBR monitoring programs do incorporate ambitious data collection across multiple scales, allowing assessments to explore natural and anthropogenic influences. Innovation comes from the incorporation of the human side of the impacts of poor water quality, with a sociological component that considers all stakeholders, changing perceptions, and appropriate communication to ensure the full value of the ecosystems is transparent and applicable to all. There is also potential to integrate official and unofficial monitoring or projects. There is a lot of fragmentation across programs, and benefit could be gained through convening and bringing together projects and data from different sources.

methods and approaches that are applicable to the GBR?

An updated coastal and marine M&E approach needs to be relevant across catchment to reef ecosystems plus tropical marine waters. However, commonalities exist across temperate programs that have been developed for other large systems with multiple pressures and multiple stakeholders. The review incorporates other programs exploring different approaches to assessment across large scales and multiple stakeholders. This question considers other programs, with different methods and approaches that could be (or should be) applicable to the GBR. The GBR is one of the most managed systems in the world, yet its enormity, complexity, and limited and fragmented partnerships between local, state, federal, and catchment to Reef users make monitoring it challenging and costly. Whilst there is no perfect solution, there are approaches that could add value to the current monitoring programs with comparable features.

1.2 Conceptual diagram

Monitoring and evaluation can be many things depending on the question being asked, and the audience that is receiving the information (Jacobson et al., 2014; Kusek, 2010; McPhail & Brodie, 1995). Monitoring typically requires a set of indicators that can, in some form, provide information on key aspects of coastal and marine systems, such as the health of ecosystems or the ecosystem services derived from ecosystems. M&E is an integral tool for policy development and when successful, can provide objective, reliable information about the impact and effectiveness of environmental policies (Perrin, 2012). M&E should be an adaptive process, constantly improving existing policies and developing better ones (Anthony et al., 2015; Bang et al., 2021; Borja et al., 2008; Graham & Hicks, 2015) (Figure 1).

The GBR has one of the most comprehensive coastal and marine water quality monitoring programs in the world, with key indicators being measured, monitored, and assessed from the adjacent catchment to the nearshore and offshore (Day et al., 2019; Day, 2022). The GBR has been monitored over complex spatial and temporal scales, with the Long-Term Monitoring Program (LTMP) collecting information on corals, fish and crown-of-thorns starfish (COTS) since the early 1980s (Emslie et al., 2008; 2020; Fabricius et al., 2023; MacNeil et al., 2019; Schaffelke et al., 2010). This long-term dataset has allowed robust assessment of the many changes within the GBR and provided important baseline data to detect and understand trends (Emslie et al., 2015; 2020; MacNeil et al., 2019). The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (P2R program), including the inshore water quality monitoring program measures agricultural management practice adoption, models predicted pollutant loads from changes in those agricultural practices, measures pollution loads and collects data for water quality, corals and seagrasses (Carroll et al., 2012; Carter et al., 2021a; Smith et al., 2012; van Grieken et al., 2019; Warne et al., 2022; Waterhouse et al., 2012). The GBR Marine Monitoring Program (MMP) has focused on the collection of coral, seagrass and water quality data from the inshore GBR, producing surveys and reports on the health of inshore coral, seagrass and water quality every year over the last 15 years (Carter et al., 2021b; Emslie et al., 2020; McKenzie et al., 2023; Mellin et al., 2019; Moran et al., 2023; Petus et al., 2016; 2019; Thompson et al., 2023) (Table 1).

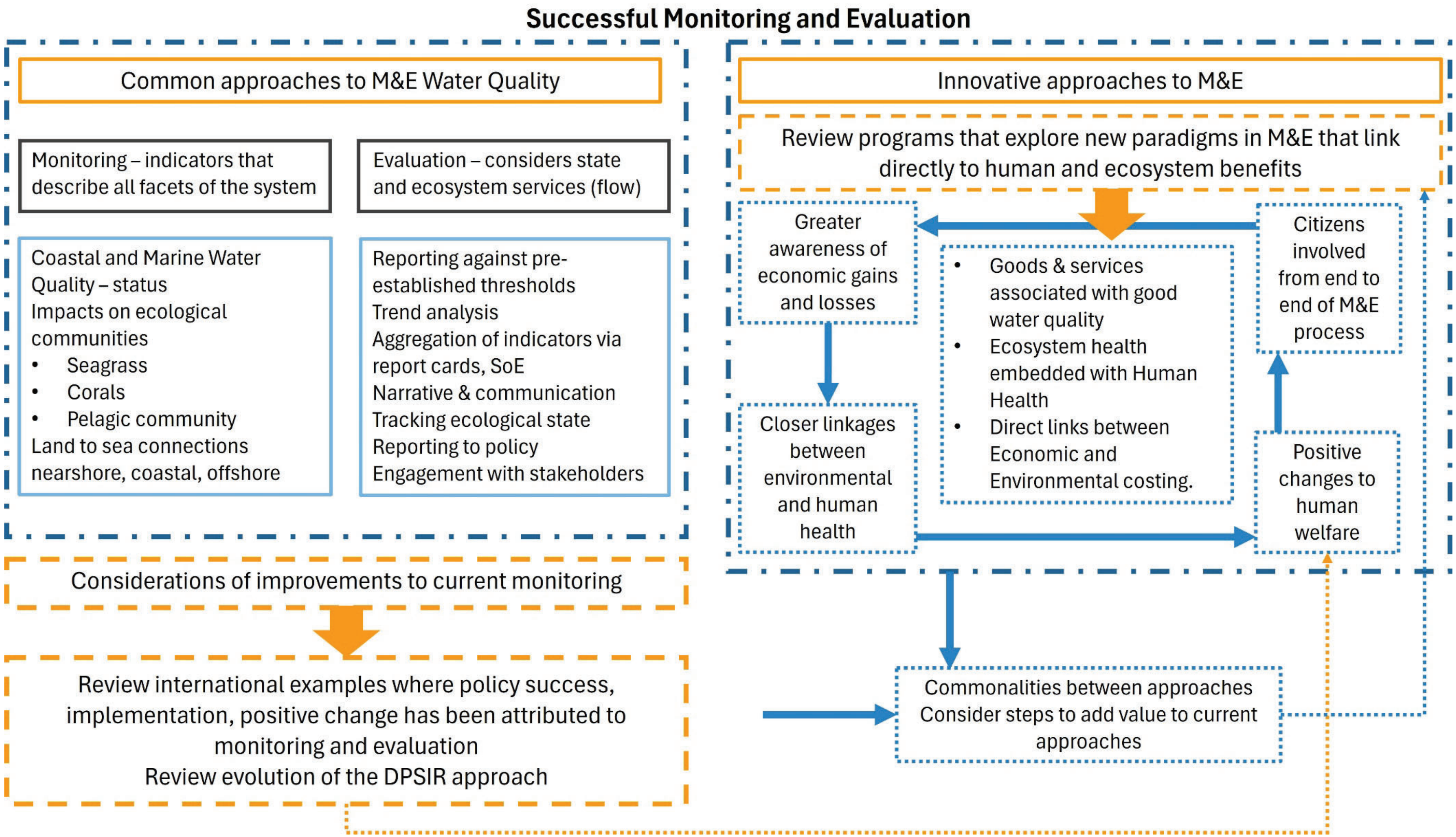

Figure 1. Conceptual diagram for Question 8.2 providing a general description on how it relates to the primary question. Boxes on the left identify many of the aspects of current approaches to GBR M&E for coastal and marine water quality, with monitoring focused on measuring status of water quality and ecological systems. Evaluation focuses on tracking ecological state and reporting to policy. Boxes on the right identify common concepts that are being increasingly used in M&E. Orange dotted lines demonstrate the review of current national and international literature on approaches which are moving beyond the common aspects resulting in greater success in their M&E approaches. Success is not defined in this diagram but will be clarified during the review.

Table 1. Summary of past and current monitoring programs carried out in the GBR that have been incorporated into the reporting framework.

Type of program	Aims	Description of M&E components
Long-term Monitoring Program (LTMP)	Measures the status and trend of reefs over a large area of the GBR.	Annual surveys with more than 25 years of coral, fish and COTS surveys[6]. Indicators include coral bleaching, COTS, coral disease, juvenile corals, coral-eating snails, reef fish species abundance, diversity, length, and biomass, and sharks (Emslie et al., 2020; Mellin et al., 2019; Russ et al., 2008).
Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (P2R)	Monitoring and modelling occur from paddock scale through to subcatchment, catchment, regional and GBR-wide. Monitoring of inshore water quality and ecosystem health in partnership with the GBR Marine Park Authority (GBRMPA), Australian Institute of Marine Science (AIMS), James Cook University (JCU), CSIRO & the University of Queensland (UQ).	The framework for evaluating and reporting progress towards Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) targets through the Reef Water Quality Report Card (Carroll et al., 2012). Methods to create report card include:[7] • Ground cover monitoring. • Catchment loads monitoring. • Catchment loads modelling. • Marine monitoring. • Marine modelling. • Wetland condition. • Human dimensions. (Kuhnert et al., 2015; McCloskey et al., 2021; McKenzie et al., 2023; Moran et al., 2023; Thompson et al., 2023; Turner et al., 2013).
Social and Economic Long-Term Monitoring Program (SELTMP)	GBR human dimension indicators relating to social, economic, cultural, and governance aspects of the GBR.	Initiated in 2011. Monitoring of GBR catchment region, tourists, tourism operators, commercial fishers, Australian residents and residents of regional GBR catchments (Curnock et al., 2014).
Reef 2050 Integrated Monitoring and Reporting Program (RIMReP)[8]	Integrated monitoring and reporting of all indicators provide GBR managers with information to guide decisions, track progress against the Reef 2050 Plan.	Launched in 2014 displaying and reporting on nearly 80 datasets/monitoring programs including all the programs listed in this table. RIMReP reports on a comprehensive and up-to-date ecological, social and cultural understanding of the GBR. The Program's primary purpose is to drive resilience-based management and track progress against the objectives and goals outlined in the Reef 2050 Plan(Condie et al., 2021; Emslie et al., 2020; McLeod et al., 2022; Mellin et al., 2020).

Many measures of success in current coastal and marine water quality M&E have been achieved in these long-term programs with ecological information on current status shared between management, stakeholders, government and the public, facilitated by up-to-date information on the status and trends of the ecosystems within the GBRMP and the pressures that can impact on them (Emslie et al., 2020; Fernandes et al., 1999; 2005; Green et al., 2014). Whilst many other coastal and marine systems have long-term monitoring programs, few, if any, are as intrinsically linked to the adjacent catchment

[6] Long-Term Monitoring Program - Annual Summary Report of Coral Reef Condition 2020/21 | AIMS
[7] https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef
[8] Reef 2050 Integrated Monitoring and Reporting Program | GBRMPA

monitoring programs as the GBR through the P2R program (Carroll et al., 2012; Greening et al., 2014). The left-hand side of the conceptual figure outlines the many measurements collected through these monitoring programs, with a focus on the attributes that are specific to coastal and marine water quality monitoring for the GBR.

The conceptual diagram presented in Figure 1 shows a process of steps from monitoring to evaluation which include adaptive management. This is not new for the GBR, where M&E programs have already informed planning and management tools for the GBR, such as marine spatial planning (Day et al., 2019) and adaptive management (McCook et al., 2010). However, despite the collection of complex information from the monitoring programs, there are not always clear lines of messaging from the data to policy to people (Dale et al., 2016; Gooch & Rigano, 2010; Waters, 2022).

The innovative approach then focuses on a set of components that are increasingly part of national and international programs for water quality. The different areas between current GBR and future innovation suggest a disconnect which can impede progress towards achieving water quality and catchment management targets, as indicated by the 2020 Reef Water Quality Report Card. Improvements to current M&E could focus on better integration of existing monitoring programs and the implementation of new M&E frameworks that could shed more light on why targets are not being achieved and opportunities to motivate landholders to implement practice management. M&E could be improved by enhancing the reporting of the connections between societal factors and environmental conservation for resolution of conflicting views. This can be achieved through application of relatively new concepts in monitoring and evaluation such as marine natural capital, which embeds environmental services into long-term monitoring, highlighting the benefits of environmental health with human survival (Figure 1).

1.3 Links to other questions

This synthesis of evidence addresses one of 30 questions that are being addressed as part of the 2022 SCS. The questions are organised into eight themes: values and threats, sediments and particulate nutrients, dissolved nutrients, pesticides, other pollutants, human dimensions, and future directions, that cover topics ranging from ecological processes, delivery and source, through to management options. As a result, many questions are closely linked, and the evidence presented may be directly relevant to parts of other questions. The relevant linkages for this question are identified in the text where applicable but the primary question linkages are listed below.

Links to other related questions	**Q7.1** What is the mix of programs and instruments (collectively and individually) used in the Great Barrier Reef catchments to drive improved land management actions for Great Barrier Reef water quality benefits and how effective are they? **Q8.1** What are the co-benefits e.g., biodiversity, carbon, productivity, climate change, and drought resilience, of land management to improve water quality outcomes for the Great Barrier Reef? Concepts that are relevant to the combined outputs of Themes 1, 2, 3, 4, 5 and 6.

2. Method

A formal Rapid Review approach was used for the 2022 Scientific Consensus Statement (SCS) synthesis of evidence. Rapid reviews are a systematic review with a simplification or omission of some steps to accommodate the time and resources available[9]. For the SCS, this applies to the search effort, quality appraisal of evidence and the amount of data extracted. The process has well-defined steps enabling fit-for-purpose evidence to be searched, retrieved, assessed and synthesised into final products to inform policy. For this question, an Evidence Summary method was used.

2.1 Primary question elements and description

The primary question is: ***What are the key attributes of successful monitoring and evaluation programs to support coastal and marine water quality management, and what examples are there of innovative monitoring and evaluation frameworks, methods and approaches that are applicable to the Great Barrier Reef?***

Description of primary question elements and definitions are summarised in Table 2 and Table 3.

S/PICO frameworks (Subject/Population, Exposure/Intervention, Comparator, Outcome) can be used to break down the different elements of a question and help to define and refine the search process. The S/PICO structure is the most commonly used structure in formal evidence synthesis methods[10] but other variations are also available.

- **Subject/Population:** Who or what is being studied or what is the problem?
- **Intervention/exposure:** Proposed management regime, policy, action or the environmental variable to which the subject populations are exposed.
- **Comparator**: What is the intervention/exposure compared to (e.g., other interventions, no intervention, etc.)? This could also include a time comparator as in 'before or after' treatment or exposure. If no comparison was applicable, this component did not need to be addressed.
- **Outcome:** What are the outcomes relevant to the question resulting from the intervention or exposure?

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[9] Cook CN, Nichols SJ, Webb JA, Fuller RA, Richards RM (2017) Simplifying the selection of evidence synthesis methods to inform environmental decisions: A guide for decision makers and scientists. *Biological Conservation* 213: 135-145 https://doi.org/10.1016/j.biocon.2017.07.004

[10] https://libguides.jcu.edu.au/systematic-review/define and https://guides.library.cornell.edu/evidence-synthesis/research-question

Table 2. Description of question elements for Question 8.2.

Question S/PICO elements	Question term	Description
Subject/ Population	GBR ecosystems. Coastal and marine water quality management.	GBR, Great Barrier Reef World Heritage Area, Inshore and Marine (coral, seagrass) Coastal and marine water quality management: Assessment, adaptation, evaluation, monitoring, Coral reefs, reefs Coastal and marine areas of the GBR: enclosed and open coastal and inshore NRMs, Large scale marine systems managed across multiple stakeholders
Intervention, exposure & qualifiers	Water quality change. Monitoring & assessment adaptation, acceptance.	M&E to consider ecological, social and economic outcomes.
Comparator (implied in question))	How do other monitoring and evaluation programs compare? Measures of success.	Monitoring and evaluation success. Integrated, multi-disciplinary M&E. Catchment to Coast, Catchment to Reef programs. Stakeholder Assessment Definition of success (criteria, uptake, change, communication).
Outcome & outcome qualifiers	Attributes of successful evaluation, how does that impact on positive outcomes?	Evaluation of assets. Ability to monitor and evaluate against a set of objectives. Successfully track ecological state. Can cope with complex interactions – alter, affect, change, influence. Timeframes of impacts for the GBR, expected delay in management response.

Table 3. Definitions for terms used in Question 8.2.

Definitions	
GBR ecosystems	Great Barrier Reef World Heritage Area (GBRWHA) Marine ecosystems: Coral, seagrass, pelagic, benthic + plankton communities (if relevant). Coastal ecosystems: estuaries, mangroves, floodplains.
Monitoring and Evaluation (M&E)	Monitoring is the periodic assessment of programmed activities to determine whether they are proceeding as planned. At the same time, evaluation involves the assessment of the programs towards the achievement of results, milestones, and impact of the outcomes based on the use of performance indicators.
Success	Measures of success can include greater definition of connectivity, stakeholder partnerships, local community involvement, direct connection with policy change, clear and successful messaging. Consideration of cumulative impacts, integrated monitoring, novel monitoring, modelling and policy tools. Information to support decision making and improved management. Achievement of program objective(s) and provision of information for managers for decision making to protect/maintain/restore the assets determined to be of value to the community/population.

2.2 Search and eligibility

The Method includes a systematic literature search with well-defined inclusion and exclusion criteria.

Identifying eligible literature for use in the synthesis was a two-step process:

1. Results from the literature searches were screened against strict inclusion and exclusion criteria at the title and abstract review stage (initial screening). Literature that passed this initial screening step were then read in full to determine their eligibility for use in the synthesis of evidence.
2. Information was extracted from each of the eligible papers using a data extraction spreadsheet template. This included information that would enable the relevance (including spatial and temporal), consistency, quantity, and diversity of the studies to be assessed.

a) Search locations

Searches were performed in:

- Scopus
- Elsevier Science Direct
- Google Scholar

b) Search terms

Table 4 shows a list of the search terms used to conduct the online searches.

Table 4. Search terms for S/PICO elements of Question 8.2.

Question element	Search terms
Subject/Population	Great Barrier Reef, marine ecosystems, coastal ecosystems, catchment, human welfare, stakeholder
Exposure or Intervention	Catchment, marine pollution, human impacts, water quality To limit the large number of returns given the searches included international literature, specific terms were used around the selected M&E approaches.
Comparator	Evaluation of change (current and predicted) Temporal, spatial, trend, pattern, coast, region, policy, user, community
Outcome	Integration, monitoring, policy implementation, human welfare, human benefits, ecosystem benefits, successful interventions, attributes of successful evaluation

c) Search strings

Table 5 shows a list of the search strings used to conduct the online searches.

Table 5. Search strings used for electronic searches for Question 8.2.

Search strings
("Great Barrier Reef" OR gbr) AND (monitoring OR evaluation OR success* OR DPSIR OR "marine natural capital" OR pollution* OR stakeholder OR assessment))
(“coral reefs” or reef) AND (tropical OR subtropical OR temperate)) AND (coast* OR marine OR ocean OR sea) AND (monitoring OR evaluation OR success OR DPSIR OR “OneHealth” OR "marine natural capital" OR pollution* OR stakeholder OR assessment)
(seagrass) AND (monitoring OR evaluation OR success OR DPSIR OR "marine natural capital" OR pollution* OR stakeholder OR assessment)

d) Inclusion and exclusion criteria

For this review, the following caveats or limitations should be noted when applying the findings for policy or management purposes:

- The focus was on frameworks with relevance to the GBR and did not focus on details around methods, technologies and/or indicators to keep scope manageable.
- Papers that demonstrated positive benefits from the use of different monitoring and evaluation methods were included.
- Given the extremely high number of returns on research that was associated with monitoring and evaluation for marine and coastal areas, only recent literature post-2000 was included. Monitoring and evaluation is a dynamic landscape, constantly changing and evolving, and the restriction to recent years will be the most relevant to the GBR and current policy setting.
- Exclusion criteria focused mainly on studies that were not directly comparable to the GBR water quality monitoring.

Table 6 shows a list of the inclusion and exclusion criteria used for accepting or rejecting evidence items.

Table 6. Inclusion and exclusion criteria for Question 8.2 applied to the search returns.

Question element	Inclusion	Exclusion
Subject/Population	GBR, coastal ecosystems, marine systems.	If no relevance to GBR, either through approach or ecosystem (i.e., offshore waters).
Exposure or Intervention	Monitoring and Evaluation and Success, "marine natural capital".	No clear management outcomes.
Comparator (if relevant)		
Outcome	Analysis of benefits, analysis of successes approaches. Describes evaluation of change – currently and how is this predicted to change over time.	
Language	English	Non-English
Study type	Review papers, description of monitoring and evaluation programs.	Not relevant to coastal or marine water quality or corals or seagrasses.
Accessibility to Authors	Includes items accessible to authors via institutional access, e.g., Scopus, Web of Science, ResearchGate, Google Scholar, etc.	All items were accessible
Other comments		Some items were excluded in the second screening because: 1: No direct information on M&E. 2: No direct information relevant to coastal and marine water quality monitoring. 3: Does not represent a successful M&E program. 4: Too broad - include components of M&E program such as monitoring indicators which were not considered under this review. 5: Outside of impacts relevant to GBR coastal and marine water quality. 6: Pre-2000 papers that were outside of time thresholds.

3. Search Results

A total of 13,711 studies were identified through online searches for peer reviewed and published literature. A total of 70 studies were identified manually through expert contact and personal collections, which represented less than 1% of the total body of evidence. Out of the 13,711 items, 8,911 studies were excluded for not being in scope and a further 4,362 duplicates were excluded leaving a total of 438 online studies taken through the initial screening, plus 70 manual additions. Based on the exclusion criteria, a further 264 studies were excluded during the second screening including limited evidence of successful criteria that was applicable to the GBR. This left 244 studies eligible for inclusion in the synthesis of evidence (Table 7) (Figure 2). No studies were unobtainable.

Table 7. Search results table, separated by A) Academic databases, B) Search engines (i.e. Google Scholar) and C) Manual searches. The search results for A and B are provided in the format X of Y, where X is the number of relevant evidence items retained and Y is the total number of search returns or hits.

Date (d/m/y)	Search strings	Sources	
A) Academic databases		Scopus	Science Direct
15/12/2022	*("Great Barrier Reef" OR gbr) AND ("monitoring" OR "evaluation)" OR success OR "DPSIR" OR "marine natural capital" OR “water quality”* OR stakeholder OR assessment)*	*52 from 148*	*48 from 186*
15/12/2022	*("coral reefs" OR “seagrasses”) AND ("monitoring" OR "evaluation" OR "success" OR "DPSIR" OR "marine natural capital" OR pollution* OR “water quality” OR assessment)*	*230 from 9,607*	*52 from 2,942*
Sub total		*282 from 9,755*	*100 from 3,128*
B) Search engines (Google Scholar)			
15/12/2022	*("Great Barrier Reef" OR gbr) AND ("monitoring" OR "evaluation" OR success OR "DPSIR" OR "marine natural capital" OR water quality* OR stakeholder OR assessment)*	*56 from 828*	
	Total items online searches	***382 + 56 = 438 taken through initial screening***	
C) Manual search			
Date	Source	Number of items added	
	Devlin and Wenger personal library	*26 (MD) and 10 (AW)*	
	Mendeley SCS database	*39*	
	Recommended by reviewers	*5*	
	Total items manual searches	***70 (0.5%)***	

Whilst the standardised evidence synthesis method has merit when there is a specific question around a GBR topic, such as pesticides and their impacts, it is difficult to apply many of the same steps given the broadness of the question. If M&E methods and techniques are considered, then there is a plethora of literature in terms of what works, success and failures and how this could inform the monitoring of the GBR. Using more specific search terms helped reduced this number but given that we were looking at international approaches where we could measure success of an M&E program or component, it was difficult to reduce this to a manageable figure, with specific search terms still returning large number of papers. Many of the exclusions were done after the literature searches and were time consuming, particularly when trying to identify a measure of success, which was not always the main part of the paper, requiring abstract and discussion review for many papers. Properly assessing the literature requires quality time e.g., on average 1 paper per hour is needed with over 200 papers examined, with over 29 days dedicated to only extracting the evidence. Meetings, emailing and writing took time from the more detailed evaluation of evidence. Search strategies missed a considerable number of important references which had to be identified using other means, including papers on socio-economic factors in the GBR, and many of the current monitoring papers for GBR. The tables for the data extraction and appraisal were quite rigid and hard to use at the beginning of the project.

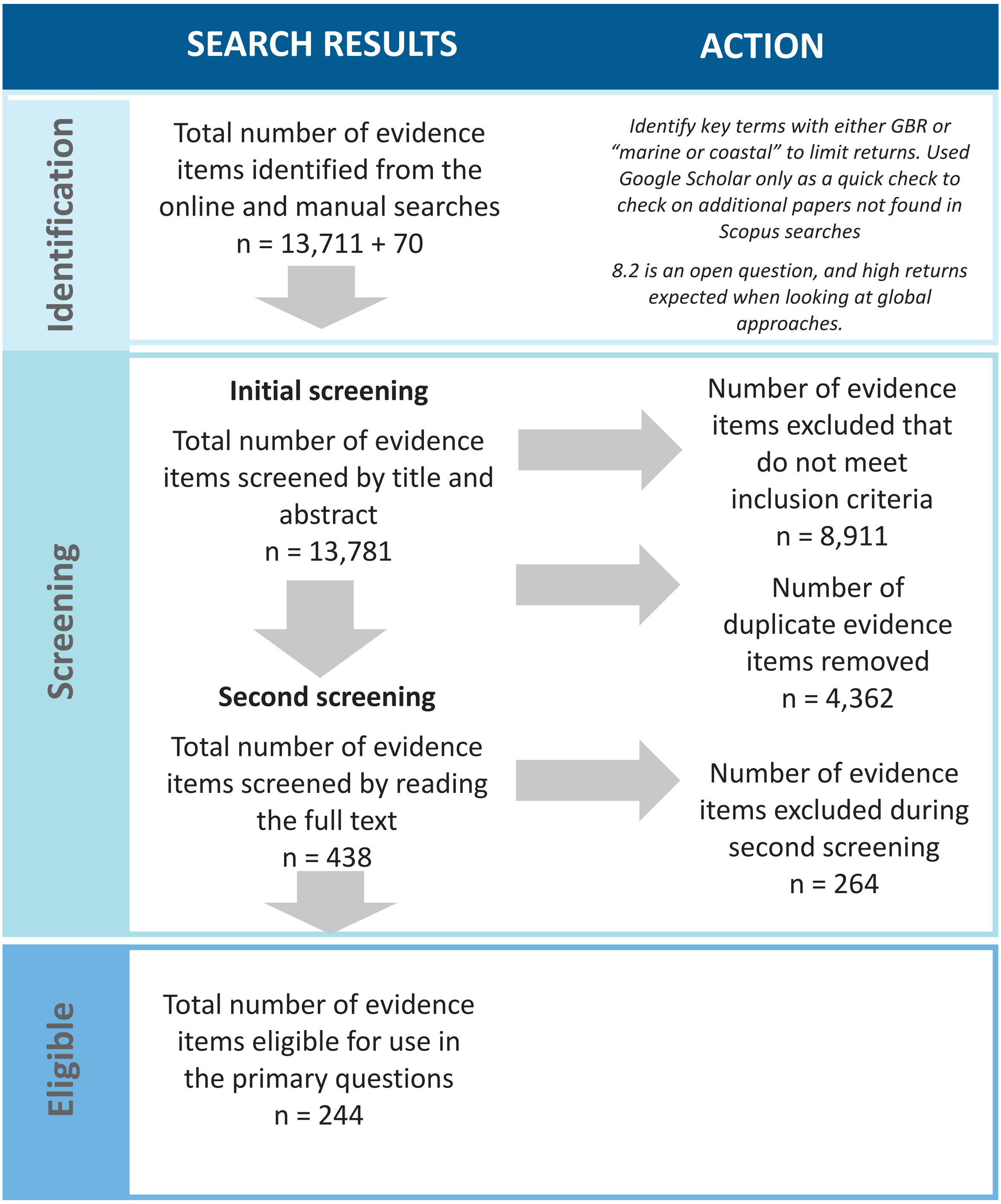


Figure 2. Flow chart of results of screening and assessing all search results for Question 8.2.

4. Key Findings

4.1 Narrative synthesis

4.1.0 Summary of study characteristics

Searches were conducted across two online databases of peer reviewed literature (Scopus and Elsevier) with an additional 70 studies added manually through expert contact, author's knowledge and reviewer's suggestions. Studies reviewed were classified by their alignment with novel M&E approaches and/or status of M&E on the GBR. The search identified 244 studies directly or indirectly addressing M&E programs or components of programs that could improve current GBR monitoring for coastal and marine water quality.

Out of those 244 references, 9 were focused on GBR governance with 57 papers representing or reporting on some aspect of current GBR M&E. Five papers explored M&E frameworks alongside MPAs and 9 addressed technology in terms of adding success to M&E programs. In terms of timing, 240 papers were from 2000 and beyond, with 52% of the papers published from 2016 onwards. Whilst one of the main inclusion criteria was for papers to be published post-2000, four papers prior to 2000 were included to provide references around the earlier approaches for M&E which includes one of the primary papers for describing ecological goods and services (Moberg & Folke, 1999), the early multi-criteria analysis for the GBR (Fernandes et al., 1999; McPhail & Brodie, 1995), and an early, seminal integrated water quality study in the Florida Keys (Suman, 1997).

4.1.1 Summary of evidence to 2022

Identifying attributes of success

Monitoring and evaluation play a critical role in coastal and marine water quality management, providing evidence of management actions and guiding decision-making processes for implementation of successful strategies to mitigate and improve marine water quality. Effective implementation requires proper planning, including the identification of indicators and targets (Fernandes et al., 1999; Lamont et al., 2022), which can then track progress towards a desired state (for example, improvements in water quality, agreed targets, stakeholder consensus).

Environmental monitoring has evolved from a single pressure-state response process to fully integrated frameworks encompassing ecosystems, pressures, stakeholders, and policy (Allain et al., 2017; Hernández-Delgado, 2015; Kies et al., 2020). Monitoring in the GBR primarily focuses on reporting indicators in coral, fish, and water quality categories, with the RIMReP program merging these indicators into user-friendly portals and report card formats, (Bayliss & Fischer, 2020; Beeden et al., 2014; Carter et al., 2021b; Marshall et al., 2019a; Mellin et al., 2020). However, the indicators are not linked within the reporting framework with economic and social indicators which are still presented separately from environmental indicators, therefore direct linkages to quantify the environmental impacts on societal indicators are lacking (Bayliss & Fischer, 2020; Marshall & Curnock, 2019). Additionally, the inshore water quality monitoring data collected as part of the Marine Monitoring Program (MMP) (e.g., Moran et al., 2023) is not currently integrated in the Reef Water Quality Report Card. The lack of integration makes it hard to understand how that portion of the program informs the overall understanding of the state of the GBR.

Success can be measured in many ways and can be quite different for the monitoring versus the evaluation components. This review describes those measures of success against attributes (Table 8). Many of these attributes can improve components of an M&E program, and each program will require bespoke approaches of many of these attributes to ensure success in implementation, uptake and long-term positive change. The types and combinations of M&E interventions that have the greatest likelihood of reducing risks of water quality impacts at the least cost with minimum social, economic and political disruption and greatest environmental gains (Atkins et al., 2011a; Carlson et al., 2022; Rees et al., 2022) depends on many factors. A summary of attributes of M&E that have been linked to measures of success in M&E programs for coastal and marine water quality management are presented in Table 8.

Table 8. Attributes of M&E that have been linked to measures of success in M&E for coastal and marine water quality management.

Attribute	How does this contribute to success within a M&E program?	Supporting references
Ability to report on complex interactions within the catchment to coast system, connecting drivers, pressures, ecological state, and impacts.	Decision support systems can enhance communication, knowledge transfer and interaction among scientists and policymakers, facilitating engagement among stakeholders in the process and enhancing the perceived legitimacy of the decision-making process. Technology is a key part of the integration of complex interactions.	Cave et al., 2003; De Valck & Rolfe, 2018; Kok et al., 2020; Mahrad et al., 2020; Mao et al., 2022; McCarthy et al., 2017; Oesterwind et al., 2016; Rolfe & De Valck, 2021; Thorburn & Wilkinson, 2013
Clearly demonstrating the performance of management actions against environmental outcomes (successful implementation).	Steering the management and implementation toward intended results or outcomes. This can be achieved through policy, regulation (e.g., MPAs), user engagement, clear communication, and engaged stakeholders.	Bawole et al., 2013; Cox et al., 2017; Cvitanovic et al., 2013; Hooper et al., 2019; Russell et al., 2013; Yee et al., 2015
Ability to demonstrate interdependence between biological and human wellbeing.	Clear connection between biological systems from the human ones, engaging society to care for those systems. Linking environmental metrics to human health wellbeing to encourage novel interventions. Responsibility for marine environment related to personal consequences of not acting.	Gordon, 2007; Mooney et al., 2009; Redford et al., 2022; Richmond et al., 2019; Ross & Carter, 2013; Trivedy, 2020
Ability to connect healthy marine system with high value economic assets. Linking environment to economic gain.	Identifying both environmental and economic value of a system creates a logical pathway for greater protection. Communities are directly part of the environmental-human feedbacks, and there is much greater success in consensus. Demonstrating clear economic and societal benefits that come from having a healthy marine environment.	Börger et al., 2020; Campbell et al., 2012; Chiesura & De Groot, 2003; Dasgupta, 2021; Hooper et al., 2019; Knudby et al., 2014; Moberg & Folke, 1999
Ability to connect wide range of stakeholders with positive environmental outcomes.	There has been demonstrable success if M&E include a wide range of voices and concerns. Embedding people into decision making within M&E provides opportunities to showcase links between environment and societal benefits**.** When communities are directly part of the environmental-human feedbacks, success is achieved by greater consensus and participation.	Lau et al., 2019; Loder et al., 2019; Schläppy et al., 2017 Darling et al., 2019 Birkeland, 2004; Darling et al., 2019; McClanahan et al., 2009; Wolanski et al., 2004

In the GBR, management processes have evolved from focusing on zoning and protected areas to including a "catchment to reef" approach that addresses pollutant loads from land-based activities (Brodie et al., 2012; McPhail & Brodie, 1995). The P2R program, a key component of GBR water quality management, integrates monitoring and evaluation tools to track change from subcatchment to coastal zones, measuring agricultural practices, pollutant loads, and water quality parameters (Carroll et al., 2012; Smith et al., 2012). The MMP, another component of the P2R program, focuses on collecting data on coral, seagrass, and water quality in the inshore GBR, providing valuable information on the impacts of pressures and land-based runoff (McKenzie et al., 2023; Mellin et al., 2019; Moran et al., 2023; Thompson et al., 2023). Data integration occurs under RIMReP, which aligns multiple monitoring programs operating in the GBRMP (Commonwealth of Australia, 2021; Hedge et al., 2017). While challenges exist in achieving cohesion and communication among the various monitoring programs, the established reporting pathways and communication products facilitate successful data dissemination to stakeholders (Hedge et al., 2017).

The GBR is facing multiple stressors, with large scale declines in coral cover being measured over the past few decades (Hughes et al., 2015, 2018; refer also to SCS Q1.2/1.3/2.1, McKenzie et al., this SCS). However, two of the most significant pressures on the GBR come from outside of the marine waters. Climate change with warming waters is the key pressure facing the GBR, with consecutive coral bleaching events having major impacts on coral cover throughout the GBR (Hughes et al., 2015; 2018; refer also to Questions 2.2, Fabricius et al., and 2.4, Uthicke et al., this SCS). Marine pollution is another key driver for impacts, predominantly in the nearshore waters, which originates from the GBR catchment area (Brodie et al., 2012; refer also to Questions 3.2, Collier et al., 4.2, Diaz-Pulido et al., 5.1, Negri et al., and 6.1, Chariton & Hejl, this SCS). High flow events result in high levels of nutrients and sediment discharging into the GBR and driving impacts in inshore reef and seagrass communities (Petus et al., 2019). Whilst it is difficult to monitor all aspects of the environment, an M&E program should consider the multiple interactions in the marine and coastal zone. The GBR is one of the most managed (and studied) systems in the world, yet there are still gaps, and many targets are failing to be reached. Thus, improvements to M&E outcomes could be through holistic and integrated approaches that build on the success of the current monitoring programs, recognising what works, and focusing on where additional components could be added to improve how the M&E can influence policy and implementation.

The principal, formal M&E reporting mechanism for the GBR as an entire system is the five yearly GBR Outlook Reports (GBRMPA, 2009; 2014a; 2019) and the 2014 Strategic Assessment Report (GBRMPA, 2014b). The past three consecutive Outlook Reports have evaluated the state of the system, including water quality, and have identified the ongoing failure to effectively mitigate the declines in water quality and many other aspects. Whilst there are many factors that have played a part in the lack of progress in this area, this review will focus on how M&E approaches can improve the likelihood of successful mitigation and positive outcomes.

Ability to report on complex interactions can improve success of M&E programs

Improvements in monitoring and evaluation outcomes within M&E programs can be achieved through the ability to report on complex interactions within a catchment to coast system, connecting drivers, pressures, ecological state, and impacts (Atkins et al., 2011b; Elliott et al., 2017). One such well known framework that has achieved many positive results is the DPSIR framework, which incorporates Drivers (D), Pressures (P), State (S), Indicators (I), and Response (R). The DPSIR framework is a widely used approach to understand interconnected layers and measure the driving forces of change (Berkström et al., 2012; Borja et al., 2006; Elliott et al., 2017; Kristensen, 2004; Martin et al., 2018; Patrício et al., 2016). Simple messaging and clear linkages between human-induced drivers, pressures, state, impacts, and human welfare are crucial to drive successful uptake of monitoring outcomes into evaluation processes into policy implementation (Berkström et al., 2012; Borja et al., 2006; Elliott et al., 2017; Kristensen, 2004; Martin et al., 2018; Patrício et al., 2016).

DPSIR frameworks act as decision support systems which can enhance communication, knowledge transfer and interaction among scientists and policymakers, facilitating engagement among stakeholders and enhancing the legitimacy of the decision-making process. Drivers and pressures can be complex and difficult to measure, and understanding the interactions between human drivers and ecological pressures is a key component to any M&E program, particularly one that spans from land to sea and multiple stakeholders (Oesterwind et al., 2016). The DPSIR framework has been adopted by the European Environment Agency and others (Atkins et al., 2011a; 2011b; Borja et al., 2006; Patrício et al., 2016; Rogers & Greenaway, 2005) and describes a framework for assessing the causes, consequences and responses to change in a holistic way. DPSIR works as a systems-based approach capturing key relationships between society and the environment and is regarded as a philosophy for structuring and communicating policy-relevant research about the environment. DPSIR frameworks highlight the interlinked relationships between social and environmental factors and have been used in marine systems in many different places (Kristensen, 2004) including coral reefs (Darling et al., 2019; Hedge et al., 2017; Rehr et al., 2012), seagrasses (Azevedo et al., 2013) and managing catchment to coast processes (Bowen & Riley, 2003; Langmead et al., 2009; Le Gentil & Mongruel, 2015; Maccarrone et al., 2014; Pirrone et al., 2005).

The DPSIR framework encompasses: 1) Drivers, which are the key demands by society and creates 2) Pressures and recognises that 3) State changes and 4) Impacts then require a 5) Response by society (Kristensen, 2004; Patrício et al., 2016). In the context of the marine environment, the overarching Drivers of social and economic development change refers to the need for food, recreation, space for living, and other basic human needs which are delivered through fisheries, recreational sites, bioremediation of waste, and so forth. Incorporating socio-ecological indicators into a monitoring and evaluation framework can be a key strategy for improving consensus across stakeholder groups. Use of the DPSIR framework to connect social needs and economic concerns can achieve success in M&E catchment to coast systems (Bell, 2012; Bowen & Riley, 2003; Fang et al., 2021; Lewison et al., 2016; Piet et al., 2015).

Ability to demonstrate the connection between biological and human wellbeing

Many environmental monitoring programs focus on the environmental aspects of the system. Whilst this is important, it can sometimes have the effect of separating out biological systems from human ones, disengaging society from caring for those biological systems. M&E should demonstrate interconnected systems, where our ability to survive without intact ecosystems will and is becoming increasingly difficult if we continue to diverge human health from environmental sustainability (Cork et al., 2016; Niner et al., 2022; Sweet et al., 2021; Trivedy, 2020). Connecting our own wellbeing and long-term health to the state of the environment can drive successful outcomes through the M&E process and create a sense of urgency around ensuring policy implementation and reaching environmental targets.

The **One Health** approach, developed from human health and climate concerns provides some integral messaging about the need to integrate society and environment into assessments of marine state. One Health is an approach calling for "the collaborative efforts of multiple disciplines working locally, nationally, and globally, to attain optimal health for people, animals and our environment", as defined by the One Health Initiative Task Force (Atlas, 2012). One Health is a cross-sectoral and transdisciplinary approach that emphasises the fundamental ways in which the health of humans, natural and built ecosystems are interdependent recognising the links between human health and a range of environmental concerns including biodiversity, climate, freshwater, food, harmful chemicals, and healthy oceans (Anchita et al., 2021). One Health has been applied to many different systems to explore the interactions with human health, including COVID 19 (García Pinillos, 2021), the impact of environmental changes on infectious diseases (Johnson & Lichtveld, 2017; Machalaba et al., 2018; Mubareka et al., 2023) and environmental changes linked to increases in emerging diseases (Anchita et al., 2021; Destoumieux-Garzón et al., 2018). One Health is rising on the agendas of national and international organisations with broad support for the approach evidenced by the establishment of several national agencies, networks, and research consortia (Kelly et al., 2020).

The One Health approach is flexible, with underlying interdependencies transferrable to many components of the natural system, including the GBR. Whilst the One Health approach has traditionally concentrated on aspects of disease, particularly emerging zoonoses in terrestrial systems, there is a growing awareness on its applicability to marine systems (Fleming et al., 2006) with recognition of the potential direct impact of coastal and marine water quality on human health, both detrimental and beneficial. Areas identified include global change, harmful algal blooms (HABs), microbial and chemical contamination of marine waters and seafood, and marine models and natural products from the seas. Examples of One Health approaches in coastal and marine systems include the role of marine pollution in exacerbation of disease in aquaculture (Glidden et al., 2022; Stentiford et al., 2020) and the rising urgency around antimicrobial resistance (AMR) (Henriksson et al., 2018). This increasing recognition can be found in the small but important number of papers that explore One Health and the marine environment in novel ways including marine litter and biological function (Morrison et al., 2022), the interdependencies for Arctic Health (Ruscio et al., 2015), HABs (Backer & Miller, 2016; Turner et al., 2021), environmental legal intervention (Kheng-Lian et al., 2016), the interdependence between human health, aquaculture and fisheries (Jamwal & Phulia, 2021; Stentiford et al., 2020), turtles (Flint, 2013), a changing ocean (Laffoley et al., 2021), coastal management (MacDonald et al., 2016) and coral reefs (Sweet et al., 2021). Sweet et al. (2021) recognised the value of a One Health approach to coral reef management, exploring the connections between coral reef health and human survival. Sweet et al. (2021) argue that marine environments are crucial components of the 'One World – One Health' framework, and that coral reefs are the epitome of its underlying philosophy. That is, they provide vast contributions to a wide range of ecosystem services with strong and direct links to human wellbeing. Current GBR M&E has very little focus on a One Health approach and as a result, policy and practice have not shown the intrinsic link between human and environmental health.

Ability to connect healthy marine system with high value economic assets

There are clear economic and societal benefits that come from having a healthy marine environment, i.e., ecosystem services, which can be used as motivation for better protection. Ecosystem services (ESS) have been defined as "the benefits people obtain from ecosystems" (Carpenter et al., 2006; Lee & Diop, 2009). These services can be divided into four ecosystem service categories: supporting, provisioning, regulating, and cultural services. Examples of marine ecosystem services include carbon storage by mangroves and seagrasses (Macreadie et al., 2021), coastal protection (Harris et al., 2018) and a multitude of goods and services associated with good water quality (Figure 3). The economic value (i.e., contribution to human welfare) of an ESS is, as with any good or service, determined by its supply and demand. The understanding and modelling of the supply of ESS has largely been taken up by natural scientists (e.g., ecologists, geographers, hydrologists). The demand side is largely determined by the characteristics of human beneficiaries of the ESS (population, preferences, distance to resource etc.). The understanding and modelling of the demand side has largely been taken up by economists (Luisetti & Schratzberger, 2023). The ESS approach emphasises how much we rely upon ecosystems (our natural capital) and the goods and services they provide to sustain our health and wellbeing (Dasgupta, 2021). Successful approaches urge the adoption of economic language and methods to make it easier to connect our environmental and financial systems together, a key criterion for the future protection of marine ecosystems (Figure 3).

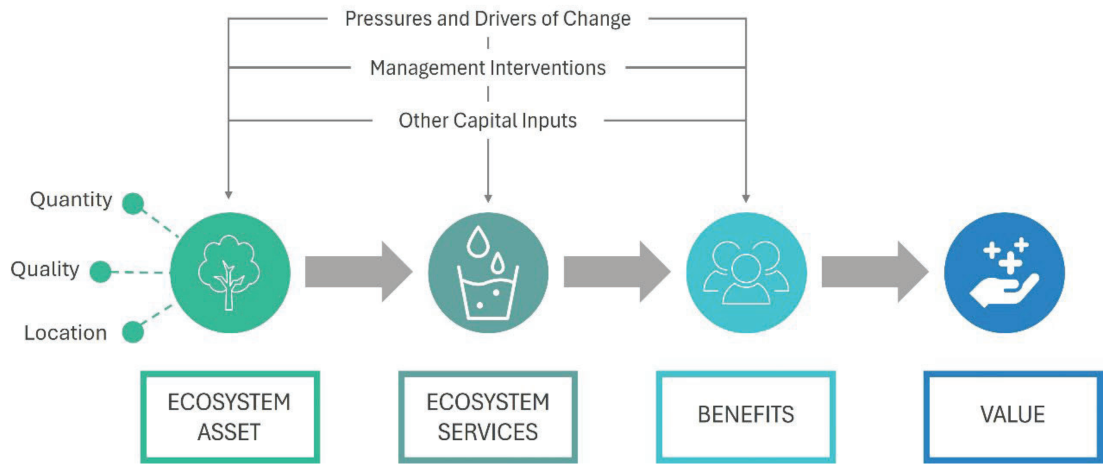


Figure 3. Example of a logic chain that links assets, services, benefits and values, and the connection between assets, services and benefits ultimately influencing the "value" of the ecosystem (Broszeit et al., 2019; Hooper et al., 2019).

The natural capital approach (Figure 4) seeks to explicitly define the economic and social values of ecosystem services to quantify how decisions made about environmental management impact on the economy and society, with the marine natural capital approach focusing on the assets that are provided by the marine environment and how ecosystem services can inform estimates of marine natural capital (Börger et al., 2020; Guerry et al., 2012; 2013; Hooper et al., 2019; Kumagai et al., 2022; Stebbings et al., 2020). The natural capital approach has more frequently been applied to terrestrial ecosystems, but it is starting to make its way into marine ecosystem management (Allen et al., 2021; Hooper et al., 2019). The UK has recently embedded marine natural capital into national environmental policy, including through England's 25 Year Environment Plan. The approach is acting as a catalyst for habitat restoration and developing nature-based solutions, improved marine spatial planning and incorporation of ecosystem goods and benefits into national economic accounting systems (Holman et al., 2005; Stebbings et al., 2020). This is particularly relevant in a catchment to coast approach such as the P2R program, where marine natural capital can be heavily dependent on upstream activities (Burdon et al., 2019; Butler et al., 2013; Gordon, 2007; Stoeckl et al., 2011).

Identifying both environmental and economic value of a system creates a logical pathway for greater protection. Ecological systems, particularly those that range across land to sea are part of a complicated system. Monitoring and evaluation programs which can incorporate this economical complexity, alongside declining budgets can provide added impetus for M&E outcomes to be an important component of government and policy decision making. To support policy making decisions on wide-ranging issues, it is important to be able to quantify value in both environmental and economic terms. Positioning ecosystem values with **marine natural capital** and/or reporting of the ecosystem services that are provided by that system improves societal and government inclusion in decision making (Cvitanovic et al., 2013; Nyström et al., 2000; 2012; Yap, 2000). Many programs that incorporate marine natural capital imbue a greater sense of urgency in marine conservation due to the recognition of the high values associated with marine natural capital (Buonocore et al., 2020a; 2020b; 2021; Chen et al., 2010; 2022; Levrel et al., 2014; Luisetti & Schratzberger, 2023). However, care must be taken to ensure the value of an ecosystem is much more than economic value, and its natural, intrinsic, environmental value must be fully considered in any natural capital approach.

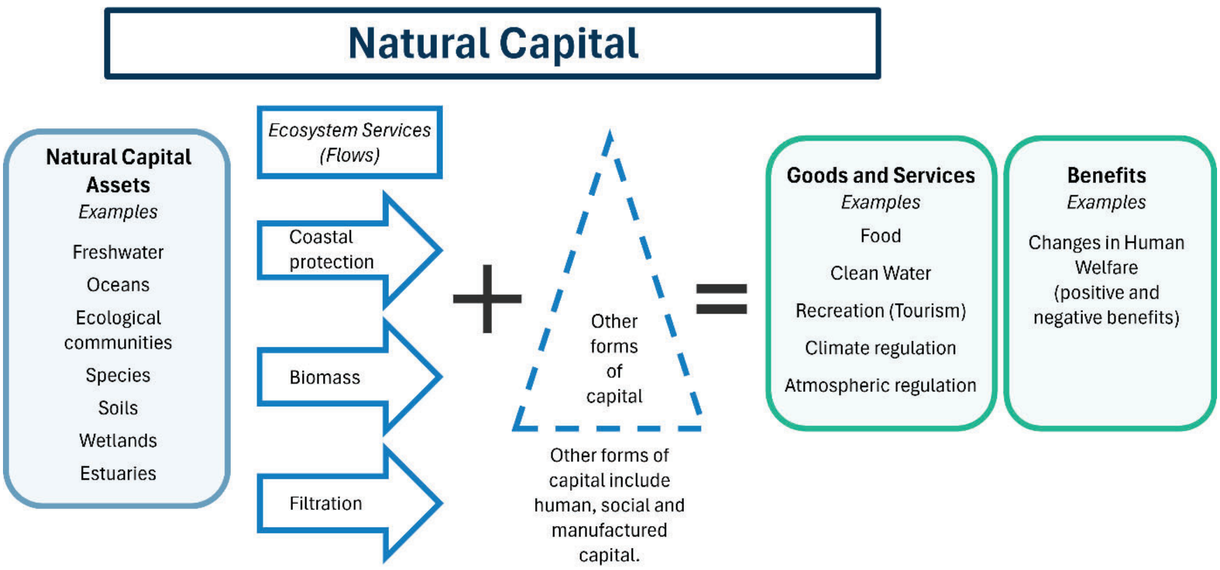


Figure 4. Natural capital represents the flow between the asset and ecosystem service into good and services and benefits for humans. Diagram adapted from NCC (1999).

Ability to connect a wide range of stakeholders with positive environmental outcomes

Monitoring and evaluation needs to be more than just the collection of indicators applied against a threshold, but a merging of social, cultural, economic and environmental outcomes (Schläppy et al., 2017). **Integration of citizen science into monitoring programs is one such way** to bring a different audience into the discussion. In addition, citizen science offers a cost-efficient way to collect valuable environmental data (Cinner & Aswani, 2007; Cortés-Useche et al., 2021; Harris et al., 2017). Citizen science incorporates the involvement and participation of the public in research projects. For example, observing and reporting data (Done et al., 2017; Golden et al., 2014; Hassell et al., 2013) or helping researchers identify species (Jones et al., 2018). Citizen science can add to monitoring and evaluation programs by the incorporation of data and information collected via non-scientific or government pathways, including the use of Indigenous knowledge (Friedlander et al., 2014; Lam et al., 2019). Citizen science is also a useful tool for management outcomes looking to engage more effectively with a greater number of stakeholders with vested interests in the outcomes of management decisions (Cvitanovic et al., 2020), incorporating conservation into local coral reef management (Cortés-Useche et al., 2021; Jones et al., 2018; Lau et al., 2019; McClanahan et al., 2015) and resolving tension across different stakeholders and opposing views (Cinner & Aswani, 2007; Daw et al., 2015; Golden et al., 2014; Larson et al., 2013; Rohe et al., 2017).

Success at reaching a greater number of stakeholders has been seen in many **citizen science** approaches (Lau et al., 2019; Loder et al., 2019; Schläppy et al., 2017). M&E outcomes can have wide ranging success if the steps taken to get to those outcomes include a wide range of voices and concerns. Citizen science is more than just volunteers collecting scientific data, though that is an important part of a citizen science approach. Citizen science can also break down complicated messaging, allowing volunteers and a range of stakeholders to be part of a solution (Hunter et al., 2018). This has been recognised in the GBR (Done et al., 2017; Gooch & Rigano, 2010; Schläppy et al., 2017) with Gooch and Rigano (2010) stating "individuals would not take responsibility for maintaining healthy waterways unless there were personal consequences for not acting". The barrier to fully engaging with concerned citizens and stakeholders may be more related to the definition of 'personal consequences' which, historically, has been focused on environmental impacts and economic gains and not the societal consequence of failing to protect our interconnected systems (Coggan et al., 2021; Thorburn & Wilkinson, 2013). Citizen science is rapidly becoming an acceptable and valuable way to increase the collection of data and offers a new way to increase knowledge about the sea (Done et al., 2017; Hesley et al., 2017). Citizen science is already an accepted part of monitoring and evaluation for the GBR, such the Great Reef Census (https://greatreefcensus.org/). In addition, programs such as the Rangers program provide support for Indigenous management that incorporates traditional knowledge (Beeden et al., 2014). Whilst the Ranger programs are much more than monitoring and evaluation, they are an example of how non-technical involvement can add great value to current knowledge.

However, it is important to recognise the limitations of the type of data that can be collected via citizen science programs, as non-technical collection of data can have wide-ranging benefit but limited uses in high quality data monitoring and evaluation. It is important for any program to identify the optimum balance of long-term technical data that provides confidence in tracking long-term changes, and the use of citizen science to bolster data collection and involve those beyond science and management.

Over recent years, there has been a continuing and accelerating appreciation of citizen science across all aspects of marine monitoring. This has culminated in the call for the United Nations Decade of Ocean Science (UNDOS) with the aim to provide a global framework for research and action to support efforts to reverse the cycle of declining ocean health (Gonçalves et al., 2022). The GBR needs to become important for all citizens, not just those in Australia. Linking to UN programs such as the UNDOS framework provides an opportunity to showcase GBR monitoring and reporting alongside other international approaches.

Citizen science can break down complicated messaging, allowing volunteers and a range of stakeholders to be part of a solution. **Embedding people into the heart of a monitoring program provides those linkages between environment and societal benefits.** One of the key components of the UNDOS vision is to focus the global community to "deliver the ocean we need for the future we want"[11]. It aims to better understand the connection that citizens have or attain with their (local) marine environment; and how marine citizen science can help foster changes towards, or maintenance of, sustainable behaviours that are relevant at a local as well as global scale. This contributes new knowledge and concepts to the

[11] United Nations Decade of Ocean Science for Sustainable Development (2021-2030) (unesco.org)

field of marine citizen science in particular, as well as to citizen science and sustainability science more generally. The GBR is unique, but it is also part of a global environment. The Australian government is a signatory body of many global frameworks and declarations. Greater emphasis on global interventions and partnerships can be a powerful communication tool.

From one end of the scale (global) to another (local), there are opportunities to embed citizen science and sustainable behaviours into GBR management. Citizen science is, again, more than just citizens being involved in monitoring; it also offers opportunities for communities to be part of the evaluation process, leading to greater involvement with decision making and governance. When communities are directly part of the environmental-human feedbacks, there is much greater success in consensus (Birkeland, 2004; Darling et al., 2019; McClanahan et al., 2009; Wolanski et al., 2004). This is particularly relevant to the GBR and P2R program- which depends on the involvement of multiple stakeholders with contentious legislation around load reduction.

Key messages from the review of M&E approaches include:

- Rates of ecosystem decline have spurred greater management efforts but have achieved little overall success as debates intensify over which factors are most important to address and how to mitigate them, making it difficult to inform policy with sound scientific consensus (Birkeland, 2004; Bischof, 2010; Darling et al., 2019).
- Reaching a shared agreement requires local, national and global participation.
- This review searched through hundreds of papers, with content taken from 244 peer reviewed papers. **The overriding message in all of the approaches is success, in terms of positive societal change, requires involvement from all, with stakeholders closely connected to the decision-making process.**
- The environment is not always a key priority for people and greater clarity of how closely human health is entwined in the natural environment could be one of the most important tools in the metaphorically large toolbox of monitoring and evaluation approaches that can contribute to the success of an M&E program.
- **A summary of the main concepts in the different types of M&E approaches is discussed in Table 9**, identifying factors that influence success, the key challenges in applying those approaches and the opportunities to take this work into the GBR M&E.

Table 9. Types of M&E programs considered in this review, with broad descriptions, factors influencing success, key challenges and the opportunities to take this work into the GBR. 'Opportunities for the GBR' identifies aspects that make it applicable to the GBR.

Components that could add to success of an M&E program	Description of the type of M&E	Factors influencing successful uptake in M&E programs	Key challenges	Opportunities for the GBR
DPSIR approach – connected frameworks	A framework for assessing the causes, consequences and responses to change in a holistic way. In the context of the marine environment, the overarching Drivers of social and economic development change refers to the need for food, recreation, space for living, and other basic human needs that are delivered through fisheries, recreation, bioremediation of waste, and Agricultural Best Management Practice etc. (Borja et al., 2006; Chen et al., 2022; Lewison et al., 2016; Patrício et al., 2016).	Long-term data, early planning, relevant data collection. Adaptive management processes.	Long standing variation in interpretation (mainly between natural and social scientists) of the different components (particularly Pressure, State, and Impact; oversimplification of environmental problems such that cause-effect relationships cannot be adequately understood by treating the different DPSIR components as mutually exclusive.	Methodology to incorporate existing monitoring programs into DPSIR framework. Reef 2050 adaptive management framework uses DPSIR framework[12] but needs clearer messaging around how existing M&E contribute to the DPSIR framework.
Providing information on Ecosystem services and Nature Based Solutions (NBS). Marine natural capital approach	This approach is about understanding the value of nature and integrating this into decisions made about the economy and society. The approach emphasises how much humans rely on ecosystems (natural capital) and the goods and services they provide to sustain human health and wellbeing. The natural capital approach provides a holistic and consistent approach to help balance the interconnected and increasing pressures on the marine environment and improves understanding of the complex trade-offs faced. NBS are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively and simultaneously benefit people and nature. Implementation of NBS will help address societal challenges through the protection,	Accurate cost estimates of the full value of the services. Incorporation into national frameworks. Requires building of strong stakeholder relationships. Need information on the benefits that flow from healthy ecosystems. They target major challenges like climate change, disaster risk reduction, food and water security, biodiversity loss and human health, and are critical to sustainable economic development and need cross-sectoral support.	Complexity of responses. Limited engagement from required stakeholders. Merging or aligning environmental and economic language. Cost Benefit analysis can differ depending on the audience. Needs a common hierarchical set of terms used to define ecosystem services to facilitate consistent messaging and collaboration.	Provides robust evidence base, suite of tools and a framework where ecological, societal, and economic information on the GBR can be brought together in a holistic way. Improved understanding and ability to make better decisions about the marine environment which link to social, environmental and economic concerns. Can build on existing programs such as SELTMP[13] that are already collecting data on social and economic wellbeing.

[12] Net-Benefits-Offsetting-Literature-review-final-draft.pdf (gbrmpa.gov.au)
[13] SELTMP (csiro.au)

Components that could add to success of an M&E program	Description of the type of M&E	Factors influencing successful uptake in M&E programs	Key challenges	Opportunities for the GBR
	sustainable management and restoration of both natural and modified ecosystems to benefit both biodiversity and human wellbeing. (Burdon et al., 2019; Lillebø et al., 2016; Niner et al., 2022).			
Connecting human and environmental wellbeing	Human and ecology considered together. Cross-sectoral and transdisciplinary approach that emphasises the fundamental ways in which the health of humans, domestic and wild animals, fungi, plants, microbes, and natural and built ecosystems are interdependent. (Atlas, 2012; Cork et al., 2016; Sweet et al., 2021; Trivedy, 2020).	Has now rapidly developed in response to evidence of the spreading of zoonotic diseases between species and increasing awareness of the interdependence of human and animal health and ecological change. This approach reflects that public health is no longer seen in purely human terms, but how declines across human, animal and environmental health impact all.	Integration requires donors, multilateral agencies and national regulations to integrate activities relevant to One Health. Requires agreed science-based targets using data management, accessibility, and sharing protocols. Shared access can be difficult across multiple agencies and stakeholders.	The health of the GBR is critical to humans and the environment. Historically, people are asked to care about the GBR due to the value of the environment, the uniqueness of the biodiversity, beauty and size. The One Health approach offers an alternative approach that incorporates that value alongside human health concerns.
Connecting people to the M&E program	Engagement and involvement of local stakeholders in data collection and marine research. (Bonney et al., 2009; Cigliano et al., 2015; Harris et al., 2017; Lau et al., 2019; Loder et al., 2019; Schläppy et al., 2017).	The quality of the data collected. Pathways between citizen activities and policy response.	Burnout with strong reliance of program on individuals. Lack of reproducibility and limited standardisation between individuals and/or organisations.	Greater awareness of environmental issues in non-academic and non-governmental audiences. Ongoing support for community-based monitoring ensures wider acceptance of societal changes.

Application of M&E frameworks to GBR water quality M&E programs

The relevance of the types of M&E programs summarised in Table 9 to water quality monitoring programs in the GBR context are discussed here.

Connected frameworks within GBR M&E

GBR monitoring to support coastal and marine management could better incorporate a broader suite of Drivers [D], which encompass the dynamic interplay of changing economic and social forces driven by markets and industry. It should also include the crucial role of modifying government policies and the activities of private industry. Furthermore, demographic changes and pressures [P] exert substantial demands on ecosystems, exerting a profound impact on the changing delivery of crucial ecosystem services. Better M&E of these Drivers could help identify factors contributing to the slower uptake of best practice management and reaching water quality targets.

The DPSIR approach has been applied in various contexts that have direct relevance to the GBR (McGrath, 2010). For instance, Newton and Weichselgartner (2014) used DPSIR to identify pollution risk hotspots in Portugal's coastal waters. Quevedo et al. (2021) aligned blue carbon and global interventions within the DPSIR framework. Integrated approaches combining DPSIR and modelling have informed coastal management (Chen et al., 2022) and incorporated socio-ecological accounting for marine ecosystems (Cooper, 2013; De Juan et al., 2015).

Within the GBR, DPSIR has been used to understand residents' responses to changes in the Whitsundays (Larson & Stone-Jovicich, 2011). Hedge et al. (2017) emphasised the need for integrated monitoring of the GBR using a DPSIR approach, including conceptual models, consensus, and realistic monitoring priorities. GBR monitoring should focus on indicators that track change and resonate with stakeholders. A decision support system for the GBR requires collaboration among natural and social scientists (Gonçalves et al., 2020; Kang & Luan, 2013; Knights et al., 2013; Ramachandran et al., 2014). Cooper (2012; 2013) suggested replacing ‘impact’ with ‘human welfare’ in the DPSIR framework to emphasise the connection between people and the environment. The P2R program has been founded on a DPSIR framework.

The sheer volume of literature around different ways of integrating the DPSIR approach into monitoring can be one of its greatest challenges in terms of uptake, presenting a complex set of structures and frameworks that have successfully used the DPSIR approach to unify components of M&E. However, in among this extensive literature, a very clear message for the success of M&E in the GBR emerges ***where future monitoring must be explicit in connecting socio-economic, ecological and management indicators*** (Atkins et al., 2011b; Azevedo et al., 2013; Bell, 2012; Borja et al., 2006)**.** Successful monitoring and evaluation should incorporate appropriate components through consideration of DPSIR, alongside traditional performance measures. Bowen and Riley (2003) describe this as the effective integration of social condition, environmental dynamics and institutional response. ***For the GBR, this would mean much clearer linkages between traditional monitoring indicators (MMP, LTMP) and societal responses.***

Work required to fully embed many of the DPSIR components has already started for the GBR in programs such as SELTMP and P2R. A comprehensive strategic assessment of the GBR and adjacent coastal zone to analyse the impacts affecting the GBR was conducted and considered cumulative impacts (GBRMPA, 2017). The comprehensive strategic assessment used a modified ‘DPSIR’ framework to assist in understanding the cause-and-effect relationships between pressures arising from drivers and activities and their impacts on the GBR ecological system and human dimensions. The DPSIR framework helped understand and manage cumulative impacts which underpinned the development of RIMReP. However, this process is not widely known and could be better visualised alongside many of the environmental indicators (Figure 5). Whilst DPSIR is already a part of existing GBR M&E, it could be more ambitious, implementing the DPSIR approach to encompass a much wider set of pressures, impacts and responses (Figure 5).

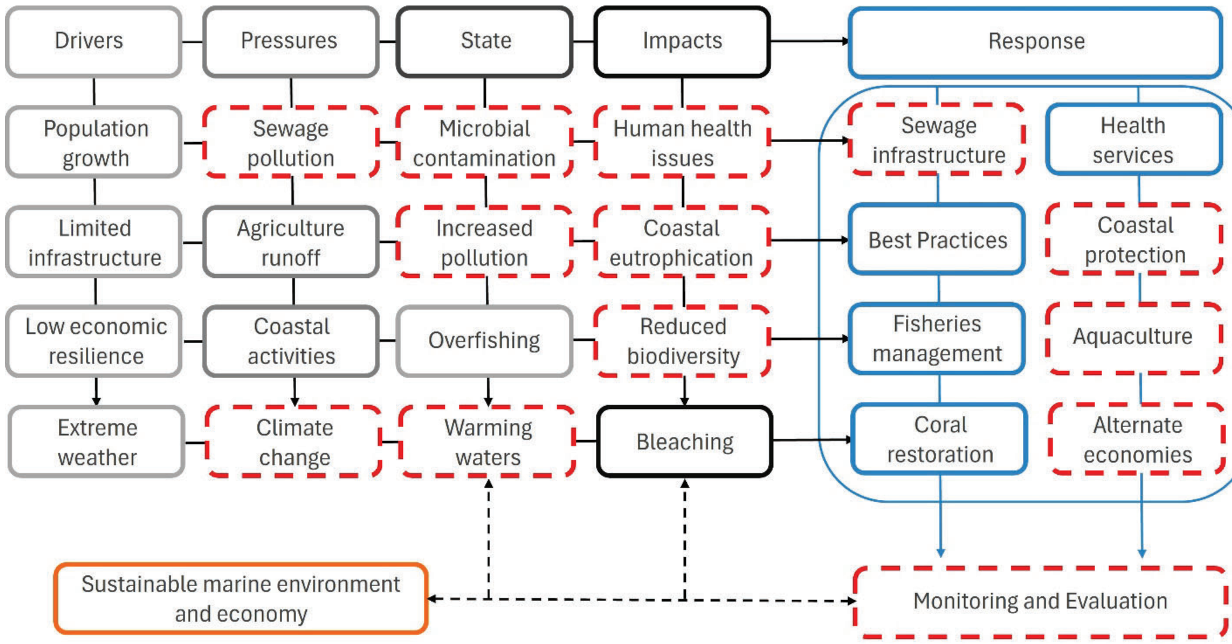


Figure 5. DPSIR approach for the marine environment with examples that are relevant to GBR water quality M&E with the components for DPSIR extracted from the 39 papers selected in the review. The black boxes represent components of DPSIR that could be extended to the GBR M&E program. Blue boxes represent the types of responses to mitigate and protect coastal and marine water quality. Red dotted lines represent pressures, state, impacts and responses that are significant to current GBR water quality issues.

Unifying human health and the GBR

The health of humans is intrinsically linked to the health of ecosystems and can be an important motivator for behavioural change (Cork et al., 2016; Destoumieux-Garzón et al., 2018; Eliakimu & Mans, 2022; Trivedy, 2020; Wakwella et al., 2023), however this is a key aspect missing from any of the GBR M&E.

The principles of One Health – defined broadly as the collaborative, multi-sectoral, and transdisciplinary approach to achieving beneficial health and wellbeing outcomes for people and their shared environment could offer a practical framework to improve M&E implementation. (Redford et al., 2022). The impacts of negative water quality are wide-ranging, affecting ecosystems but also negatively impacting humans following damage to ecosystem health and consequent socio-economic hardship (Turner et al., 2021), illustrating the complex relationships between all aspects of One Health. A One Health approach requires engagement of relevant stakeholders (government, farmers, wider industry, scientists and the public) to facilitate the design of food systems which provide human health benefits of consuming aquatic protein with positive environmental, organismal and societal impacts. Operationalising a One Health approach for the GBR would require development of metrics focused on optimising environment, human and organism health. Sweet et al. (2021), reflects that coral reefs, as canaries in the coal mine due to the sensitivity of corals to climate change and with the current emergence of a wide range of coral diseases, make ideal study systems to assess links, impacts, and feedback mechanisms that can affect both human and ecosystem health. There are well-established protocols for monitoring corals, as well as global networks of coral researchers, but there remain substantial challenges to understanding these complex systems, their health and links to provisioning of ecosystem services. Sweet et al. (2021) argue that a greater integration of coral reef research into the 'One World – One Health' framework will enrich our understanding of the many links within, and between, ecosystems and human society.

The GBR water quality M&E could incorporate elements of human health in multiple ways. Information on human or livestock health issues could be included as part of a P2R program. This type of approach could consider health issues that could be influenced by environmental health. Greater awareness of the importance of protecting and restoring the environment for human health and wellbeing could be a key attribute in future M&E. Additionally, an expanded water quality M&E program could assess antimicrobial resistant pathogens in samples as well as other contaminants like pharmaceuticals and personal care products (PPCPs), especially considering that wastewater discharge monitoring are not currently monitoring them (Nguyen et al., 2021; refer to Question 6.1, Chariton & Hejl, this SCS). Finally, an M&E program that assessed contaminant accumulation in commercially and recreationally important fisheries species could also highlight why improving water quality is important, and may identify novel champions for change, such as fishers.

Communicating the value of ecosystem services of the GBR

Conserving the capacity of reefs to generate essential services requires that they are managed as components of a larger seascape-landscape of which human activities are seen as integrated parts (Moberg & Folke, 1999). Monitoring the status and health of the marine ecosystem, and compliance with minimum standards, is a critical component of many international frameworks. This reflects the values that international communities already set on their marine ecosystem services. Many of these studies have focused on economic gains from long-term tourism, which is an important part of this discussion, however, given the current negative trajectory of many of the GBR's assets, more is needed to demonstrate the clear benefits of protecting the GBR (De Valck & Rolfe, 2018; 2019; Rolfe & De Valck, 2021). The economic benefits derived from the GBR have previously been quantified (O'Mahoney et al., 2017) with an estimate for the total Australia-wide value-added economic contribution generated in the GBR catchment area in 2012 of $5.7 billion, including economic benefits from tourism, commercial fishing, recreation and science management (refer to Question 1.1, Newlands & Olayioye, this SCS). Measuring the economic value of the GBR is a busy space, with over 40 major studies and many more for individual components at smaller scales, reviewed and summarised in Rolfe and De Valck (2021). Stoeckl et al. (2011) further quantified the economic value of the ecosystem services in a comprehensive review of both ecosystem services supplied by the GBR and the way in which activities that are carried out adjacent to those regions affect those values. An important conclusion from that seminal study is that many of the activities that occur in regions adjacent to the GBR influence the ability of the GBR to provide ecosystem services and clearly the GBR is not just a 'provider' of ecosystem services: it is also a recipient, and when the GBR receives fewer services from its surrounding ecosystems, it is less able to provide ecosystem services in return. Whilst Stoeckl et al. (2011) focused on two services (tourism and fisheries), there is also consideration of non-monetary services where at least 20 categories of ecosystem services provided by oceans using standardised accounting (www.oceanaccounts.org). Thus, existing valuations omit a large number of services and are by necessity gross underestimates of the full cost value of the GBR. For example, coastal protection through building infrastructure by healthy coral reefs, seagrass meadows and mangroves would be worth hundreds of millions each time a severe cyclone crosses the inhabited coast. Thus, despite the many barriers to quantifying the full costs, it is critical to map the ecosystem services within the GBR monitoring programs. Limited information on the value of a functioning GBR puts those very services at risk.

Monitoring of social and economic indicators has already been applied on the GBR (Curnock & Marshall, 2019; Gooch et al., 2017; Marshall et al., 2019a). The Social and Economic Long-Term Monitoring Program (SELTMP) monitors cultural services to highlight the cause-and-effect pathway between environment and people (Marshall et al., 2014; 2019a). Monitoring within SELTMP includes dedicated social science surveys to develop fuller understanding of the benefits of cultural services, and links to asset condition, at both a place-based scale (to determine impact/outcome of changes to asset status) and national level surveys to inform policy direction. SELTMP already measures many of the variables that could be relevant to marine natural capital, although not quantified in economic terms. Separate research projects have also quantified much of the economic costs that are at risk from a declining state (Coggan et al., 2021; Coggan & Whitten, 2008; Whitten et al., 2008). Current programs under RIMReP already measure multiple environmental indicators as well as report SELTMP indicators (Emslie et al., 2020; Mellin et al., 2020). However, success in M&E implementation could be achieved through ***greater cohesion between trajectories of environmental indicators and the impact on economic, cultural and social indicators. This could be further bolstered by greater support for the development of a social science method to understand the full economics, social and cultural benefits of the marine and coastal environment***. This should include ecosystem services related to protecting catchments as well.

Information on marine ecosystem services might not be enough to sell farmers on the idea of changing practices, but ecosystem services that come from protecting land and freshwater systems (including groundwater) might and should be included in any add-ons to the GBR monitoring to make sure the M&E data will influence the right people. This has been recognised in Gordon (2007), one of the first to describe win-win situations where economic benefits to graziers were a co-benefit for improving water quality.

M&E for coastal and marine water quality should measure the direct linkages between economic and environmental factors. Marine natural capital can and should be embedded in marine programs which intersect multiple stakeholders with conflicting views as a successful tool to audit economic and social consequences of a declining environmental state (Gari et al., 2015; Lewison et al., 2016). This is not new to the GBR with several publications already considering values as part of the GBR seascape (De Valck & Rolfe, 2019; Rolfe & De Valck, 2021). To lay a solid foundation for a marine natural capital program for the GBR, this work should continue to define the link between the asset, benefit and service and to communicate those benefits to all stakeholders that contribute (or benefit) from that service.

Table 10. Description of marine natural capital terms extracted from relevant literature that have relevance for GBR coastal and marine water quality programs. Components include assets, benefits, ecosystem services and logic chains with examples for the GBR.

Requirements for marine natural capital approach	Description of terms	Relevance for GBR coastal and marine water quality	Examples for GBR coastal and marine water quality
A common set of marine natural capital asset classes	Assessment Areas (catchment versus inshore assets)	Catchment, inshore, estuarine and coastal	Subcatchment activity impacting downstream.
A common set of benefits and ecosystem services	Regulating Services Cultural Services Provisioning Services	Ecosystem services can include coastal protection, filtering (good water quality), and fish nurseries.	Regulating: Carbon sequestration, coastal support. Clear coastal waters that support functioning seagrass communities. Cultural: Coastal recreational activities. Provisioning: Fish communities supported by clean water quality.
Logic chains (linking assets to societal benefits)	Facilitate coordinated work across the program and to enable the full range of positive and negative impacts of management decision making on natural capital to be evaluated.	The availability of data, indicators, and modelling tools to monitor or predict status with respect to the key attributes can be applied to the GBR.	Connections between catchment activity influencing water quality and impacts on downstream benefits.

This is particularly relevant to the current GBR water quality program. Sitting at the interface between land and sea, nearshore GBR water bodies are a key part of marine natural capital, and most impacted by upstream activities. They are also a primary feature for coastal tourism and recreation, and a critical home for diverse and productive biodiversity. Managing the condition of nearshore waterbodies supports productive fisheries, coastal economic activity and wellbeing (including in deprived coastal regions) and managing their condition requires linking land-based management with marine conservation (Niner et al., 2022; Rees et al., 2022). To do so, it is important to consider the cyclical nature of these linkages within the M&E to identify and assess relationships between ecosystem services and benefits with the social, cultural, economic and political drivers. Marine accounting in the UK (Rees et al., 2022) has identified simple activity-attribute tables which could form the basis of an enhanced catchment to coast monitoring program (Table 11).

Table 11. Activity-Attribute Impact Table indicating the relative impact of different activities on attributes of pelagic water quality (Rees et al., 2022). *White cells - no, or negligible level of interaction; P / yellows cells – Partial or localised impact; M / amber - Moderate impact in terms of magnitude and spatial extent; H / red - Significant impacts in terms of magnitude and spatial extent. Example is taken from framework developed for the UK eutrophication monitoring program with the focus on pelagic water quality and adapted from Le Quesne and Capuzzo (2022).*

Attributes / Activities	Agricultural runoff	Sewage	Urban runoff	Shipping	Recreation & tourism	Aquaculture	Fishing	Climate change
Temperature								H
Water movement								M
Salinity		P						P
Water clarity	M	M	P			P	P	P
pH								M
Oxygen concentrations		M				P	P	M
Nutrients	H	H				M		
Marine litter		M	M	P	M	P	M	
Chemical status	M	M	M	P				
Microbial pathogens	H	H		P		P		M
Phytoplankton	H	H		P		P	P	M
Zooplankton	M	M		M			P	M

Connecting people to the science in the GBR

Water quality programs in the GBR have also used citizen science, including Water Watch with the involvement of the public who collected river water during flooding events (Devlin et al., 2001) and catchment-based monitoring programs (Tsatsaros et al., 2021). Citizen science initiatives have helped with coral reef monitoring through the rapid reef monitoring program that developed simple survey sheets and trained tourists and tourism companies to survey coral reefs (Done et al., 2017). Seagrass Watch techniques have also been adapted and tested via the seagrass marine monitoring program (McKenzie et al., 2000). Limitation of funding has also been a key driver in the use of non-experts in monitoring protected areas in the GBR (Hassell et al., 2013), with long-term trends showing comparable outcomes of data collected from expert and non-experts. However, there is still potential for further citizen science programs to be applied in the GBR supporting much more than just data collection. Citizen science can be effective and could become a more prominent approach for marine and coastal conservation (Cigliano et al., 2015). There is an underrepresentation of citizen science in coastal and marine management, with Cigliano et al. (2015) citing logistics, lack of time spent on water, resourcing, lack of visibility and ownership. However, successful citizen science outcomes have shown environmental and societal benefits (Aceves-Bueno et al., 2015) that can and should benefit the GBR. Success in GBR M&E depends on embracing the diversity of people associated with different parts of the GBR, strong and mutual collaborations, honesty about credibility and building expertise of the involved citizens. It is also important to consider the partnerships between the citizens themselves, their expectations and requirements and the management audience. Interested stakeholders, with narrow interests can become active and effective advocates when participating in a cooperative and co-created M&E program.

4.1.2 Recent findings 2016-2022 (since the 2017 SCS)

This section briefly discusses how the discussions on M&E approaches has evolved over the last few years and the consequences of this on how GBR M&E can go forward. Whilst the focus is on recent literature, this question was not asked in the 2017 SCS, and thus the review builds on a trajectory of literature that encompasses a range of approaches which could be applied to future GBR M&E for coastal and marine water quality.

Current Monitoring and Evaluation:

- The GBR is a very well monitored system, with long-term datasets, robust and reproducible methodologies, a plethora of scientists and science institutions providing a depth of expertise and high-quality data to make informed and considered assessments of the changes occurring in the GBR (Kennedy et al., 2012; Marshall et al., 2014; Mellin et al., 2020; Pratchett et al., 2006; Schaffelke et al., 2010).
- Overviews on different types of monitoring components in the GBR are increasing, including a greater awareness of the economic and socio-ecological drivers in the GBR (Curnock et al., 2014; Darling et al., 2019; Gordon, 2007; Larson et al., 2015; Stoeckl et al., 2011).
- Collaborative decision making has always been a key component for GBR management, and many papers explore how the success of the program is improved by reaching a wide audience of stakeholders. However, success in enacting real change in the improvements of water quality condition is constrained by limited engagement across societal concerns (Coggan et al., 2021). The disconnect between stakeholders in the GBR has been noted in many publications prior to this SCS (Brodie & Pearson, 2016; Brodie & Waterhouse, 2012; Butler et al., 2013; McPhail & Brodie, 1995; Stoeckl et al., 2011) and articulated by Gordon (2007) who recognised that truly integrated adaptive catchment management of the GBR is only possible when biophysical, social and economic systems are linked.

What enhances success in a M&E program:

- For clear elucidation of what makes a successful M&E program, it is useful to identify what is already successful. It is not the 'lack' of information that has hindered the success of coastal and marine water quality programs. This is particularly relevant to the GBR, given the high quality and high frequency spatial and temporal information that provides the information to track change with an increasing use of high functioning models and high-resolution satellite data embedded in the water quality program (Baird et al., 2021; Petus et al., 2016; 2019; Steven et al., 2019). There is also increasing use of innovative technology to measure at higher temporal and spatial resolution (Madin et al., 2019).
- Success in current M&E comes from the integrity and depth of the monitoring data, with indicators that cover paddock scale measurements, load information, long-term water quality monitoring, wet season dynamics, corals, seagrass communities and COTS providing a density of data rarely seen in monitoring programs. Whilst the complex governance protocols that are already in place have made some aspects of the paddock to reef management difficult to manage, there are also some powerful environmental policies and adaptive management protocols which have helped to partly preserve the health of the GBR.

What hinders successful implementation from current M&E programs:

- Even with all these data, and levels of protection, the GBR still faces extreme pressures, both internally (pollution) and externally (climate). Despite the high volume of information and the ability to track change (Emslie et al., 2020), there are still high levels of contentious debate, with limited success in convincing some of stakeholders, particularly those that live and work adjacent to the GBR, of the need for large scale management responses to ensure high levels of protection (Brodie & Waterhouse, 2012; Butler et al., 2013).
- There is still much debate about the need for small and large-scale management changes throughout the GBR catchment area, with the Senate Inquiry[14] highlighting the lack of consensus from farmers (and government individuals) on the need for catchment management (Brodie and Waterhouse, 2012; Creighton et al., 2021).
- More needs to be done, in ways that have not yet been considered to successfully manage the GBR against current and future pressures.

[14] Identification of leading practices in ensuring evidence-based regulation of farm practices that impact water quality outcomes in the Great Barrier Reef – Parliament of Australia (aph.gov.au)

Ways to achieve future success:

- **Success for GBR M&E** and positive policy implementation should continue to focus on ways to assess and manage proximate causes of decline presenting proactive interventions, at state and national level to improve water quality.
- However, reaching consensus has become a critical outcome for M&E programs. It is no longer enough just to collect, measures, assess and report on environmental trajectories. Consensus building needs to be incorporated into all layers of monitoring and evaluation programs, be it a strongly supported citizen science program, or clear and concise links between environmental, economic and human health with governance systems where all have a voice (Birkeland, 2004; Bischof, 2010; Dutra et al., 2019; Hunter et al., 2018; Nyström et al., 2008; Rassweiler et al., 2020).
- Improvements to M&E can then be gained through programs that clearly elucidate a greater awareness of the economic gains and losses. Birkeland et al. (2004) talk about “ratcheting coral reefs” with three interventions: 1) develop interventions that are proactive rather than reactive—that is, focus on prevention, not just restoration; 2) deal with the ultimate causes (impacts related to economic demands), as well as the proximate causes of coral reef decline (climate, pollution, overfishing); and 3) promote responsible human behaviour.
- ***The last few years of the current SCS term has seen a rapid increase in the number of papers which explore the multi-faceted layers between the coastal and marine environment and the decisions made by and for the people who live and work within these systems***. Embedding people into the heart of a monitoring program provides those linkages between environment and societal benefits. **It is a simple but crucial message that success of M&E depends on the many layers of stakeholders, government agencies and citizens working together** (Suman, 1997).
- ***Successful implementation and positive change from an M&E program*** involves imagining of a new future, where equitable adaptive approaches are tailored to local socio-ecological context and innovative approaches which highlight the importance of the GBR beyond current expectations (Graham & Hicks, 2015). Bischof (2010) discusses the importance of community input in the role of successful reef management, where the highest degree of contention (and failure) was the lack of community in human-environment feedback systems. ***Conversely much of this literature identifies that success in M&E programs occurs when community concerns and engaged stakeholders are embedded directly in the decision-making process (Cigliano et al., 2015).***
- The terminology between the different science disciplines can be a barrier to consensus building and management uptake. **Successful approaches have, as with DPSIR and One Health, involved clear lines of communication between different agencies and encourages transparency by a common set of goals.** It is also critical to incorporate timescales when considering natural capital and the value of ecosystem services to ensure that shorter-term economic benefits derived from degrading ecosystems, such as resource extraction activities, are compared to the longer-term economic benefits of protecting an ecosystem (Albert et al., 2021).

4.1.3 Key conclusions

- At a large scale, degraded coastal habitats with reductions of the economic benefits of coastal tourism, depleted fisheries, loss of species and human diseases and loss of life are among those impacts caused by environmental, social and economic impacts of land-based pollution (Brodie & Pearson, 2016; Butler et al., 2013; Dale et al., 2016; Larson et al., 2015; Ramachandran et al., 2014; Stoeckl et al., 2011; Tsatsaros et al., 2021).
- There is an increased recognition that scientific information collected does not effectively convert into policies, plans and projects that can prevent or reduce negative environmental, health and economic impacts.
- M&E in the GBR has, in response to the size and complexity, focused on large scale. This approach has supported one of the most ambitious coral reef, water quality and seagrass monitoring programs in the world. However, this focus on large scale can sometimes miss the

small-scale issues that can be more relevant to many of the stakeholders. Disparate programs, each in its own successful way, have presented compelling evidence on the long-term trends of corals and fish, and in more recent times, seagrass. However, traditionally, this reporting has not been implicitly linked together, despite being collected in the same program and assessed together in regional report cards. Historically, the focus has been on coral reefs and less on the integrated marine system, which needs management across complicated governance, complicated ecology and mismatched timescales.

- There is a disconnect between our understanding of what is driving impacts and linking that scientific evaluation to positive change. The collection of data, and the ability to be confident in tracking and understanding change is only one small part of M&E. The success of an M&E program lies in the ability to drive change, using the information generated to track change, but also to create a narrative where environmental sustainability is strongly supported by society.
- M&E programs that have successfully driven positive change from management include those that adopt the system drivers, pressures, state, impact and responses (typically shortened to DPSIR) framework, recognise ecosystem services and marine natural capital, adopt multi-disciplinary frameworks and report on the interactions between environmental and human health, and support connections to people through the use of citizen science.
- Successful M&E approaches should continue to consider integrated approaches such as DPSIR frameworks. The current P2R program was structured around DPSIR and forms a key part of the monitoring however, linkages between different components are lacking and impeding the success of the evaluation components.
- GBR monitoring can be more clearly related to enhanced Drivers [D], reporting on the changing economic and social forces driven by markets and industry, modifying government policies and the activities of private industry, as well as demographic changes and pressures [P] – the ways these drivers place demands upon ecosystems with an impact on the changing delivery of ecosystem services.
- The GBR water quality monitoring program needs to also consider the additional pressures caused by larger scale human-induced climate change and extreme natural events. Pressures are the interface between the social and ecological components of the system. State changes are the changes in the ecosystem resulting from the pressures. It is the interactions between pressures and state that directly or indirectly affect society and economy and hence the combination of those factors that result in a monitoring program being directly related to the welfare of people (Mee & Adeel, 2012).
- Incorporation of natural capital into monitoring programs has been a successful way to bring together the system linkages between ecology, goods and services, and benefits to human wellbeing. Integrated approaches like the cross-sectoral and transdisciplinary One Health monitoring and evaluation framework, that emphasises the interconnections between the health of humans and ecosystems, are highly applicable to the GBR as a potential monitoring and evaluation approach (Borja et al., 2016; Chiesura & De Groot, 2003; Guerry et al., 2013; Russell et al., 2013). These holistic approaches also recognise the benefits of projects and programs that are relevant to a range of end-users.
- One of the key criteria for success across the literature is the integration of multiple layers of information for greater benefits and across multiple stakeholders to achieve much more ambitious improvements for coastal and marine water quality. This resonates across the programs that have been presented in this review, recognising that a common approach, a multilateral One Health strategy including citizen science-based reporting and incorporating marine natural capital could add value to the existing M&E programs.
- Finally, whilst this review has presented different approaches, there is often overlap between many of the components. The use of nature-based solutions is a key component of valuation of natural capital, with many of the assets and services identified as nature-based outcomes. One Health, whilst offering a process that interlinks environmental and human health also resonates with DPSIR approaches, and acknowledges the positive outcomes associated with assets and services. Ecosystem services are a key component of the DPSIR approach, identifying the

outcomes of the human response (Martin et al., 2018). No single program has all the solutions, but the basic and important premise is that by protecting the ocean, we protect ourselves; humans, the ocean, biodiversity, and climate are inextricably linked and action on water quality, pollution, resilience and human health must be undertaken together. A fully integrated approach to M&E will achieve what the current programs aim to do, to fully integrate across land to coastal and offshore GBR, with decision making and consensus building across all stakeholders.

4.1.4 Significance of findings for policy, management and practice

- The GBR is many things to many people, as well as one of the key biodiverse habitats in the world. Alignment of the many different user requirements with sustainability has always been a difficult process, recognised by the multi-use zoning applied by GBRMPA. The varied and multi-layered characteristics of the GBR ecosystem requires M&E criteria linking different stakeholders and competing concerns, whilst ecological state is robustly tracked by environmental, social and economic indicators.
- The concepts explored in this review incorporate multi-faceted and multi-layered understanding of the environment, including citizen science, marine natural capital, frameworks that connect drivers, pressures, state, impact and response (DPSIR) and One Health approach. The success in using interconnected frameworks and the One Health approach highlight the need to embed environmental, economic and social components of a system together, so that people with competing concerns understand the value of investment and decisions that support long-term sustainability. Agreed investments can include time, money, changes in practice, elevation of communication, and shifts in lifestyle.
- The collection of robust, high-quality data with the ability to confidently track direction of change is only one small part of M&E. In many respects, the success of a monitoring program is the ability to drive change, using the information generated to track change, and to create a narrative where environmental sustainability is strongly supported by society.
- Economic costs of environmental changes (gains and losses) need to be transparent to all stakeholders and tracked through the application and reporting of marine natural capital. The natural capital approach is about understanding the value of nature and integrating this into decisions about the economy and society.
- Citizen science offers opportunities to involve people in data collection and assessment but is also a powerful tool to embed citizens into the decision-making process.
- The One Health approach demonstrates that environmental values are intrinsically linked to human health and economics, supporting integrated decision making for both human and environment needs.
- Better and more equitable social, cultural, economic, and environmental outcomes for the GBR are possible through thinking across environmental and social concerns. This requires the M&E program to establish stronger linkages to humanity and societal concerns and by doing so, elevate Australia's understanding of the interactions and dependences of the relationship humans have with the GBR.
- A summary of attributes that could contribute to GBR M&E water quality and delivery include multidisciplinary frameworks that recognise the complex interactions between social, economic and ecological drivers; quantifying values and interactions; and enhanced engagement and community involvement.

4.1.5 Uncertainties and/or limitations of the evidence

This review does not, in any great detail, offer additional monitoring indicators. It does not present a review of current technology, recognising that ongoing work has already identified pathways to improved data collection. However, despite these gaps, the GBR monitoring program is one of the most extensive in the world, linking up paddock scale monitoring with GBR ecological indicators. There is still much to be done in terms of the direct links between a catchment-based activity or mitigation, such as reduced nutrient loads and the ecological health of the GBR and whilst the programs in place do measure components of that intrinsic link with nutrient load reduction strategies and water quality thresholds, there are still key gaps in the M&E of these connections.

The GBR has been well monitored for many years, and has several large, (generally) well-funded agencies collecting, analysing and reporting the data. Literature searches extracted many hundreds of papers that discussed different components of M&E, different types of indicators, and different types of technology that could offer some input into what makes a successful coastal and marine water quality program. However, the nuance of the searches was to find specific evidence of components of well-known programs that were not (yet) incorporated into the current programs. This was not an easy step and has been reflected in the many iterations of this review to identify components that could add success to an already well-established program.

4.2 Contextual variables influencing outcomes

Table 12 summarises the influence of each contextual variable (including climate change or climate variability and episodic events) on the question outcomes or causal relationships.

Table 12. Summary of contextual variables for Question 8.2.

Contextual variables	Influence on question outcome or relationships
Climate change (or climate variability)	One of the pressures that needs to be explored in M&E is climate change. Climate change indicators should be visualised alongside other monitoring indicators. Water quality impacts can be exacerbated by climate change, and this needs to be accounted for in M&E of coastal and marine water quality.
Marine pollution	Can be many types of marine pollution and water quality can be measured across multiple indicators. For this review the focus was more on agricultural /nutrient pollution, and interactions between upstream and downstream impacts.

4.3 Evidence appraisal

Relevance

A total of 244 studies were included in this review, and the relevance of the overall body of evidence to the question was rated as High (7.1). The relevance of the overall body of literature to the question was High (3.0) with Moderate for spatial relevance (2.1), and Moderate for temporal relevance (2.0) to the primary question.

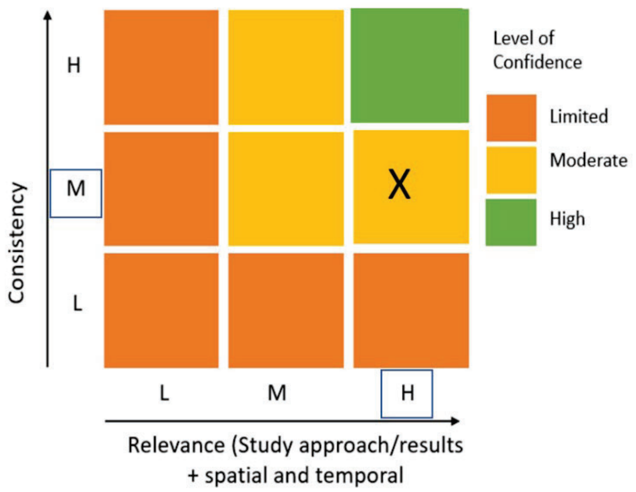
Consistency, Quantity and Diversity

Consistency: Moderate. This reflects relatively good consistency with a large number of papers for each type of monitoring, ranging across different systems and different countries, however, the range of papers and different approaches explored for this review also influence that consistency. When the papers are separated out into different types of M&E, the numbers for each approach are reduced. Thus, there is a large number of different approaches with a smaller number of papers which is reflected in the medium consistency. There is a large variability of findings regarding the question being addressed, and this reflects the complexity in processes, and diversity of the question. **Quantity**: 240 studies published from 2000 onwards were reviewed specifically addressing the question with four seminal papers prior to 2000 also included and 52% of the papers were published since 2016. **Diversity**: The High diversity of studies used for the synthesis is supported by the different types of papers within the 244 papers varying across different topics of M&E including citizen science/community consultation (30), DPSIR (39), GBR governance (9), GBR scene setting (57), Integrated approaches (28), marine natural capital (39), MPAs (5), One Health (28) and Technology (9). The depth and breadth of monitoring programs, and differences in M&E explored in the papers provide a good range of complexity and diversity in the types of M&E components.

Confidence

Confidence is Moderate, based on Moderate consistency and High Relevance. This Moderate confidence reflects the large body of literature that exists around different approaches in M&E providing High diversity, but the breadth of the literature (components, geographical locations and approaches) influences the lower score of Moderate for the consistency rating. Although relevance is High (7.1) the lower ratings for temporal and spatial relevance reflect that the majority of the literature (75%) was taken from international case studies. There were several GBR relevant studies around new, emerging and different approaches to M&E, but those represented a much smaller subset (25%) and many of those were included as background information around current M&E. Some loss of confidence could also be associated with the broader M&E categories, with many of the studies having relevant outcomes, but not always focused on coastal and marine water quality. Many of these broader studies were excluded in the second screening but there was still a very broad range of approaches and different types of terminology included in the final set of 244 papers (Table 13).

Table 13. Summary of results for the evidence appraisal of the whole body of evidence used in addressing Question 8.2. The overall measure of Confidence (i.e., Limited, Moderate and High) is represented by a matrix encompassing overall relevance and consistency.

<table>
<tr><th>Indicator</th><th>Rating</th><th>Overall measure of Confidence</th></tr>
<tr><td>Relevance (overall)</td><td>High</td><td rowspan="8">
</td></tr>
<tr><td>-To the Question</td><td>High</td></tr>
<tr><td>-Spatial</td><td>Moderate</td></tr>
<tr><td>-Temporal</td><td>Moderate</td></tr>
<tr><td>Consistency</td><td>Moderate</td></tr>
<tr><td>Quantity</td><td>High
(244 studies)</td></tr>
<tr><td>Diversity</td><td>High
(48% reviews, 32% observational, 15% experimental and 5% modelling)</td></tr>
</table>

4.4 Indigenous engagement/participation within the body of evidence

No Indigenous engagement other than literature searches around community and citizen science.

4.5 Knowledge gaps

Table 14 describes key research gaps and what the potential outcomes could be for policy/management if these research gaps were addressed.

Table 14. Summary of knowledge gaps for Question 8.2.

Gap in knowledge (based on what is presented in Section 4.1)	Possible research or Monitoring & Evaluation (M&E) question to be addressed	Potential outcome or Impact for management if addressed
What is required to implement a more integrated M&E framework?	What are the existing tools that have been applied in the GBR that have not been used to full potential? What are tools that have never been applied? What needs to be done to further integrate into the main monitoring programs?	Better use of existing information. Comprehensive understanding of what has been applied through various programs and processes that could add value to existing program. Targeted advice on what needs to be further implemented.
Better linkages between environmental outcomes and societal priorities.	How to ensure better linkages between trajectory of the environmental indicators with human and social indicators? What type of information has been or needs to be collected to inform decision making process?	Clearer linkages between GBR and human health. Greater awareness by society and government of the intrinsic link between humans and their environment.
Lack of clear overarching frameworks that incorporate different scales of human and environmental data.	Develop better connections between different indicators for greater transparency.	Robust integration of all monitoring indicators, increased response between programs with clear and transparent reporting frameworks. Reporting frameworks resonate with multiple stakeholders.
Improving the use of ecosystem services and associated costs in current M&E programs.	Definition of terminology associated with marine natural capital to ensure better alignment with environmental data. How to establish improved reporting of gains and losses of environmental and economic costs?	Environmental and economic indicators reported more cohesively. Clear pathways on links between attributes and benefits to inform management and long-term policy decisions.
Embedding linkages between environment and society into current monitoring programs.	Are there best practice examples of where/how clearer linkages have been made between traditional indicators and societal responses?	Improved communications and greater awareness of the intrinsic link between wellbeing of the GBR and society.
Why are existing mechanisms not achieving greater success in mitigation of water quality?	How much would an improved M&E approach influence the current trajectory of GBR water quality issues? Three consecutive Outlook Reports have evaluated the state of the system, including water quality, and have identified the ongoing failure to effectively mitigate the declines in water quality and many other aspects. What other issues are in play that impact on this failure outside of M&E approaches?	Further understanding of what is required to improve current status of water quality that lies outside of M&E, including ambition to achieve positive change.

5. Evidence Statement

The synthesis of the evidence for **Question 8.2** was based on 244 studies, undertaken in multiple locations and published between 1997 and 2023. The synthesis includes a *High* diversity of study types relating to monitoring and evaluation approaches (48% reviews, 32% observational, 15% experimental and 5% modelling) and has a *Moderate* confidence rating (based on *Moderate* consistency and *High* overall relevance of studies).

Summary findings relevant to policy or management action

Monitoring and evaluation of projects and programs of management actions to improve coastal and marine water quality is essential to assess environmental, social and management change, track progress towards program objectives and targets, and inform and improve current and future decision making. Monitoring is a critical element that involves the collection of data and information before, during and after implementation. Successful evaluation involves the systematic assessment of a project or program's design, its implementation, and outcomes to determine whether original objectives were achieved, identify lessons learned, deliver learning and demonstrate accountability. Across the studies included in this review, success was associated with the inclusion of holistic monitoring and evaluation approaches across multiple values, beneficiaries, and disciplines. Coastal and marine water quality monitoring and evaluation programs that have successfully driven positive change from management include those that adopt the system drivers, pressures, state, impact and responses (typically shortened to DPSIR) framework, recognise ecosystem services and marine natural capital, adopt multi-disciplinary frameworks and report on the interactions between environmental and human health, and support connections to people through the use of citizen science. The Reef 2050 Integrated Monitoring and Reporting Program and the Paddock to Reef Integrated Monitoring Modelling and Reporting programs are among the most comprehensive and integrated catchment to reef monitoring programs in the world. These programs recognise the links between drivers, pressures and state through the reporting of environmental, social and economic indicators. They also attempt to merge the complexities of the pressure-state response in user-friendly visual portals and report card formats, although the connections between environment and people, health and citizen science are not explored in great detail. Potential improvements drawn from the global evidence base include greater recognition and quantification of complex social, cultural, economic and environmental values and their interconnections, strengthening of multi-disciplinary frameworks to link to human health, and greater community engagement including direct participation in monitoring programs. A holistic ecosystem approach to Great Barrier Reef water quality management in the context of other major drivers such as climate change could also help to enhance the value of existing monitoring and evaluation programs.

Supporting points

- Successful monitoring and evaluation approaches were identified in this review from programs around the world that consider concurrent measures and indicators related to environment, economics and society. The primary integrated coastal and marine water quality monitoring and evaluation programs in the Great Barrier Reef are the Reef 2050 Integrated Monitoring and Reporting Program, the Paddock to Reef Integrated Monitoring Modelling and Reporting program and the monitoring and reporting conducted as part of the regional report card partnerships.
- Incorporation of natural capital into monitoring programs has been a successful way to bring together the system linkages between ecology, goods and services, and benefits to human wellbeing. Integrated approaches like the cross-sectoral and transdisciplinary One Health monitoring and evaluation framework, that emphasises the interconnections between the health of humans and ecosystems, are highly applicable to the Great Barrier Reef as a potential monitoring and evaluation approach. These holistic approaches also recognise the benefits of projects and programs that are relevant to a range of end-users.
- Monitoring and evaluation programs that contribute to positive changes through management actions include those that engage and represent the values of a diverse range of stakeholders

that are impacted by the decision making. This is particularly true for local and regional stakeholders but can also extend to international partnerships, large conservation agencies and international frameworks.

- Greater engagement of the community in data collection, but also in evaluation and decision making, would enhance monitoring and evaluation programs for the Great Barrier Reef and potentially lead to greater acceptance and support of changed management arrangements.
- Measures of success across different scales (relevant to different audiences) from policy to community and multiple stakeholders are important and may deliver a more robust understanding of project and program outcomes.

6. References

The 'Body of Evidence' reference list contains all the references that met the eligibility criteria and were counted in the total number of evidence items included in the review, although in some cases, not all of them were explicitly cited in the synthesis. In some instances, additional references were included by the authors, either as background or to provide context, and those are included in the 'Supporting References' list.

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Appendix 1: 2022 Scientific Consensus Statement author contributions to Question 8.2

Theme 8: Future directions and emerging science

Question 8.2 What are the key attributes of successful M&E programs to support coastal and marine water quality management, and what examples are there of innovative M&E frameworks, methods and approaches that are applicable to the Great Barrier Reef?

Author team

Name	Organisation	Expertise	Role in addressing the Question	Sections/ Topics involved
1. Michelle Devlin	Cefas	Water quality, plankton, marine pollution, monitoring and evaluation	Lead Author	All sections
2. Amelia Wenger	University of Queensland	Marine Pollution, Monitoring and Evaluation	Contributor	Writing, editing all sections